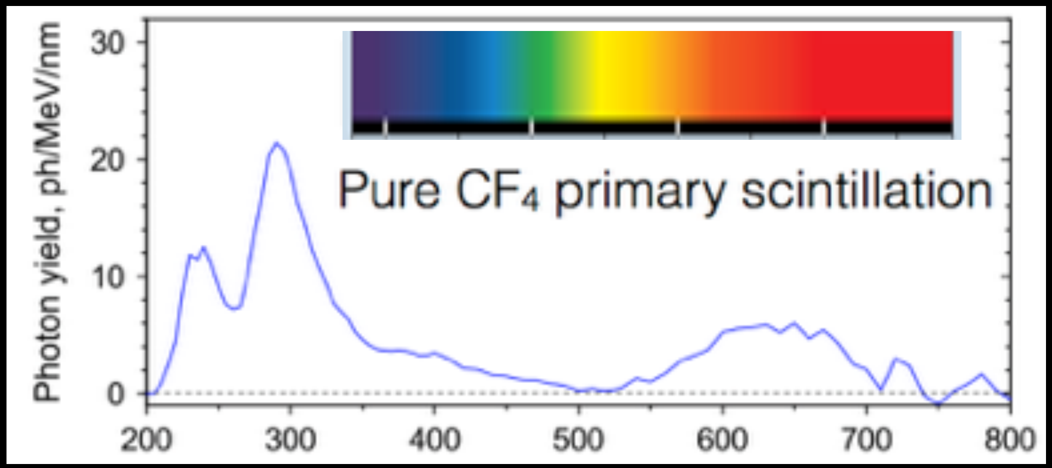
ORANGE - INFN SEZIONE DI ROMA

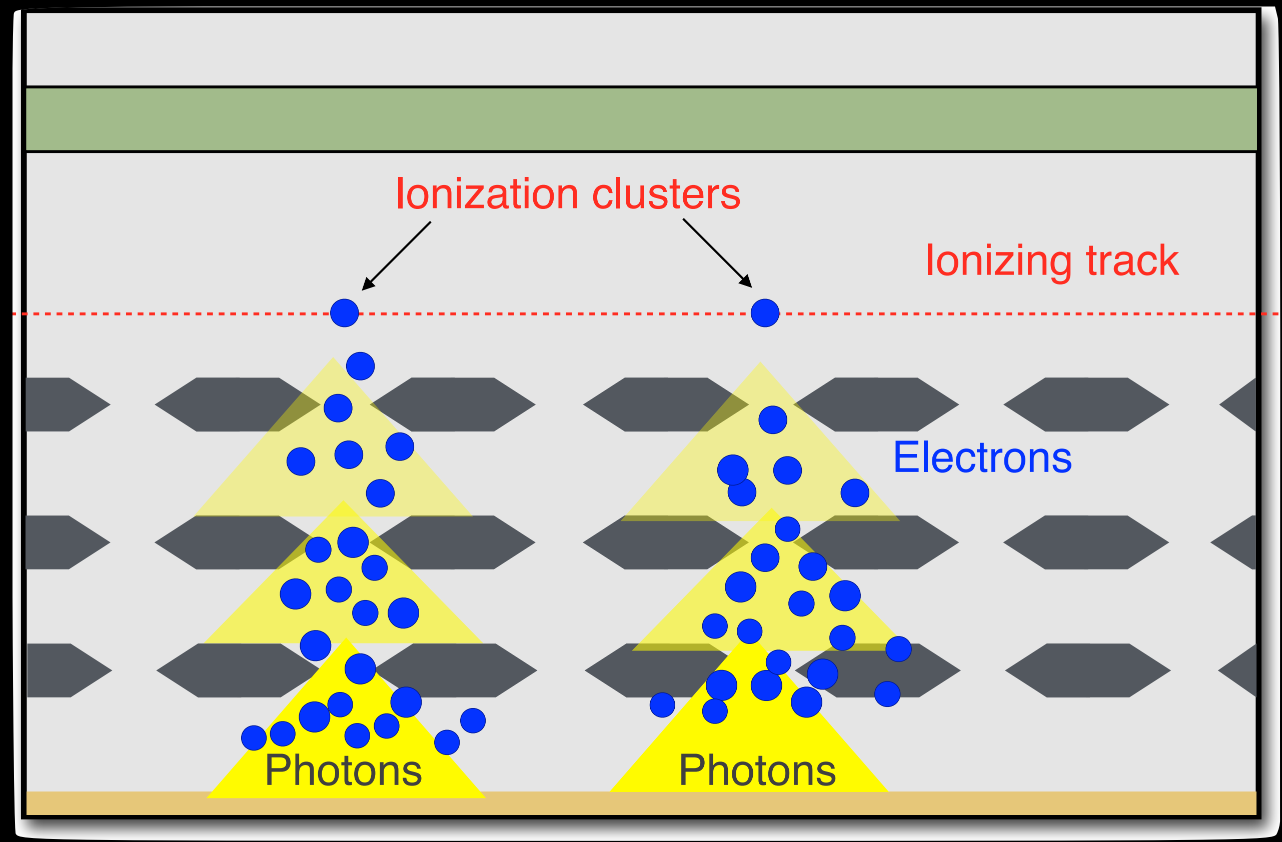
ORANGE: TRACKING PARTICLES WITH OPTICALLY READOUT GEM

LIGHT: A CHANGE OF PARADIGM

During the multiplication process, photons are produced along with electrons by the gas through atomic and molecular de-exitation; Amount and spectrum of emitted light depends on the gas mixture;



Clusters produced a charged track in a Triple GEM will generate a lot of electrons and photons

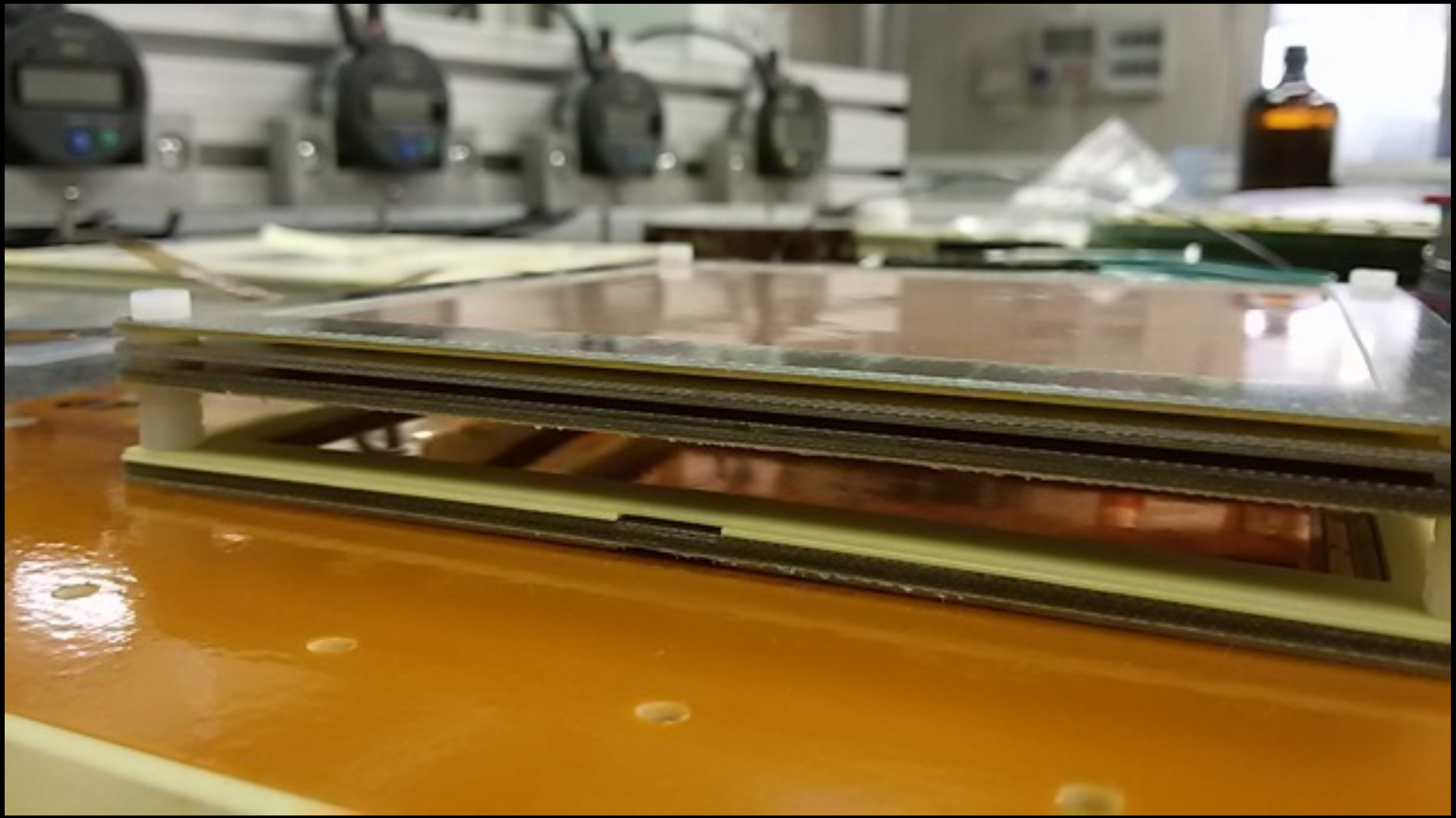


Electrons can be collected by the last GEM electrode and photons can by "seen" through a suitable transparent window

THE ORANGE PROTOTYPE

The Optically Readout GEM prototype was obtained by stacking three 10x10 cm^2 standard GEMs:

- 10 mm drift gap;
- 2 mm transfer gaps.



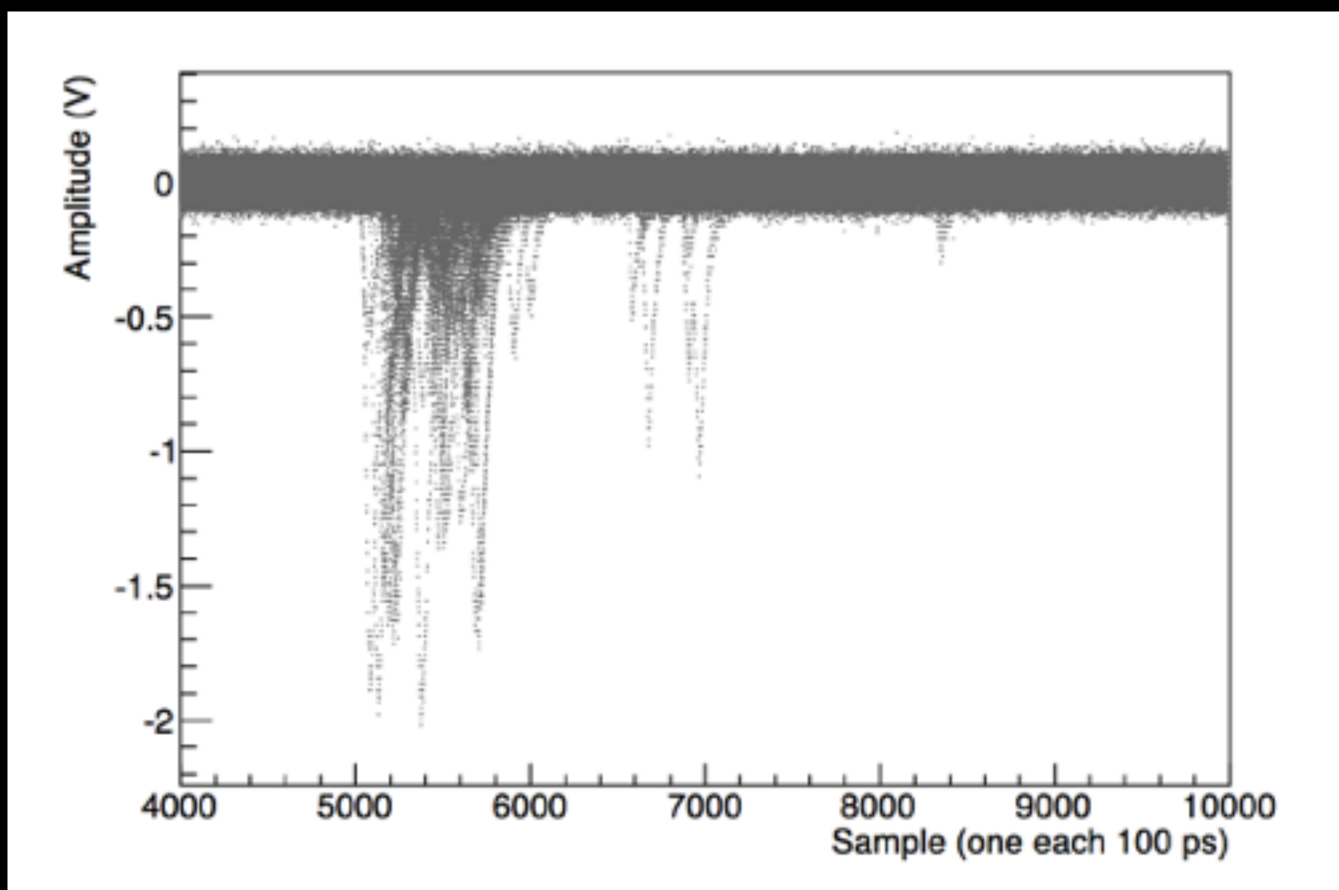
A transparent window is placed below the last GEM to close the volume.

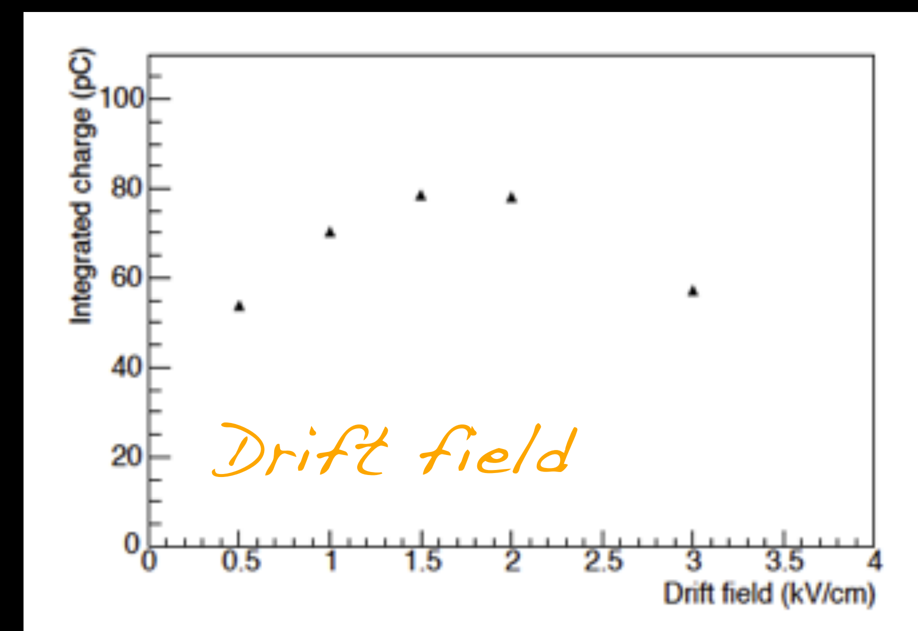
The optical sensor it therefore not in contact with the gas.

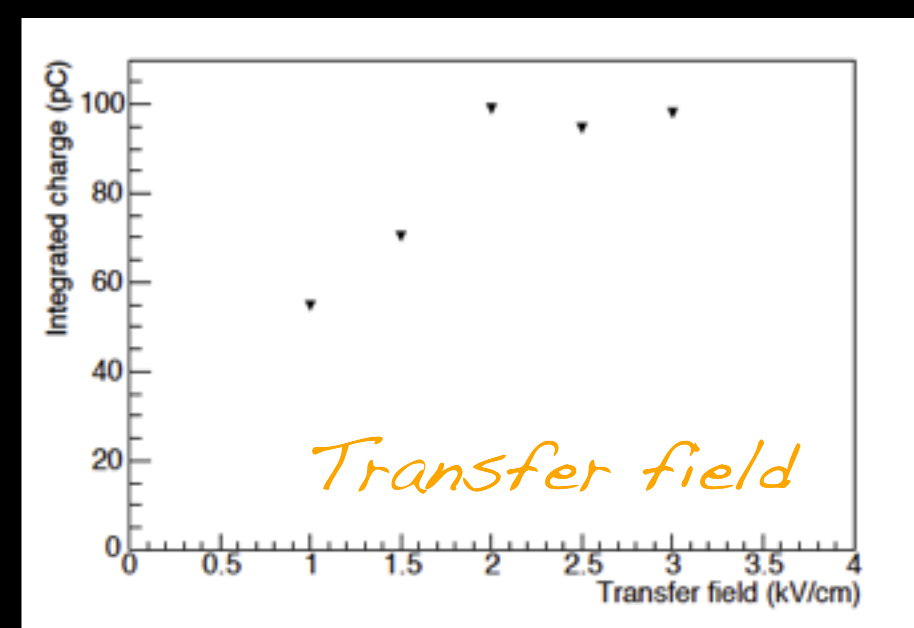
Binary He/CF_4 mixtures (mainly 60/40) were used.

APRIL 2015: PMT MEASUREMENTS

Measurements performed by using a PMT allowed to optimize the electric fields miximising the detector transparency;

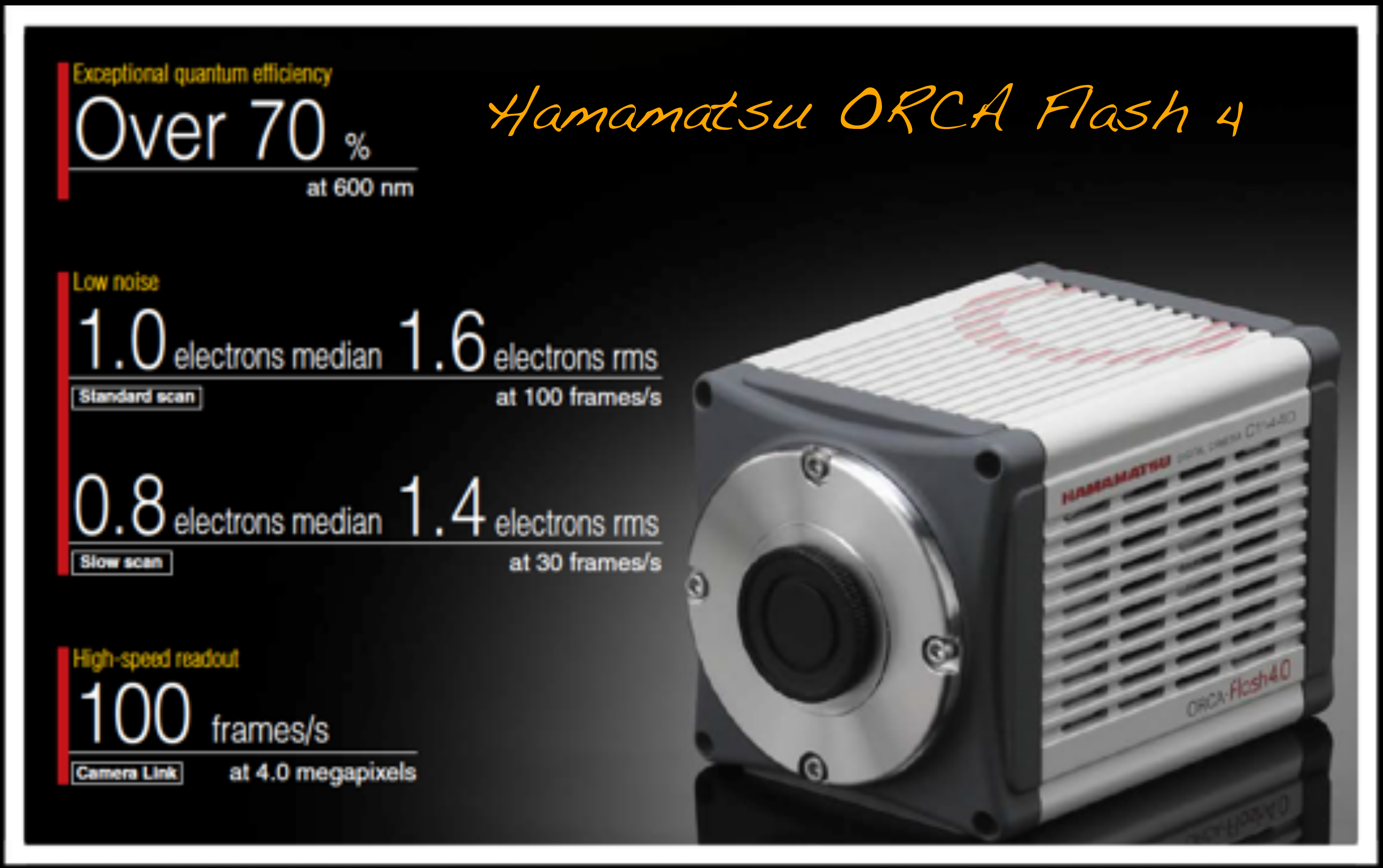




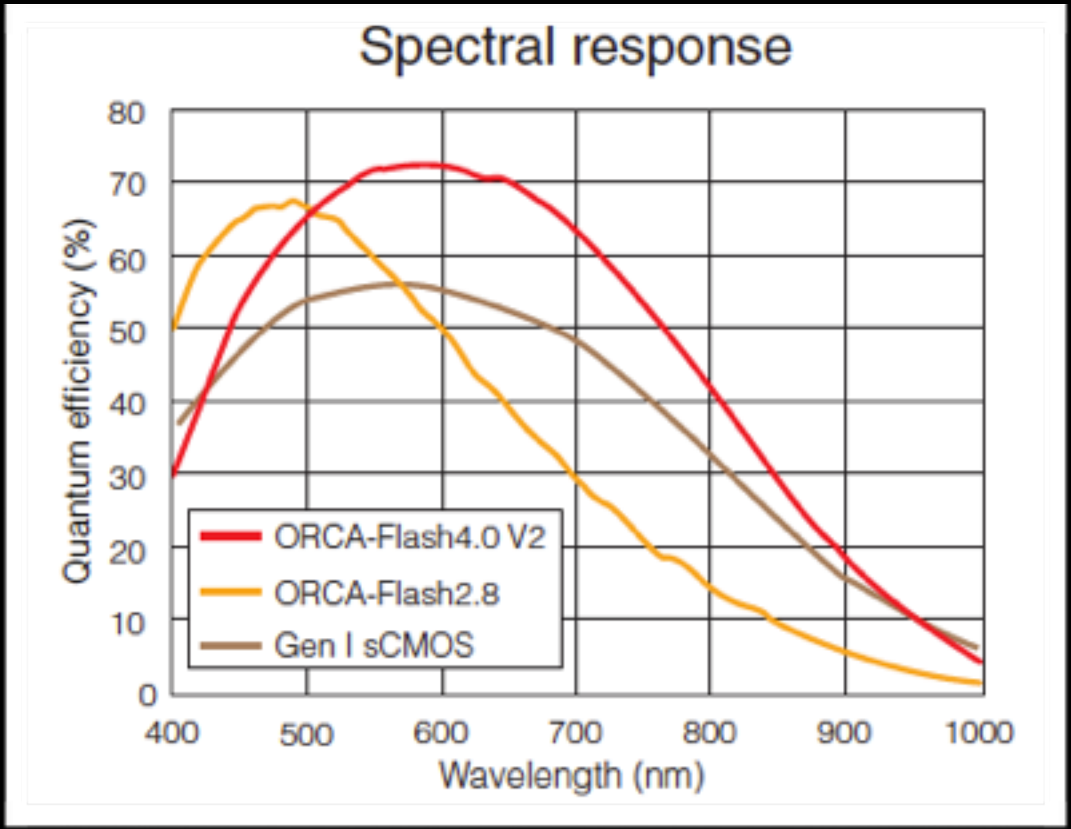


We decided to operate with a drift field of 1.5 kV/cm and transfer fields at 2.0 kV/cm

THE CMOS CAMERA



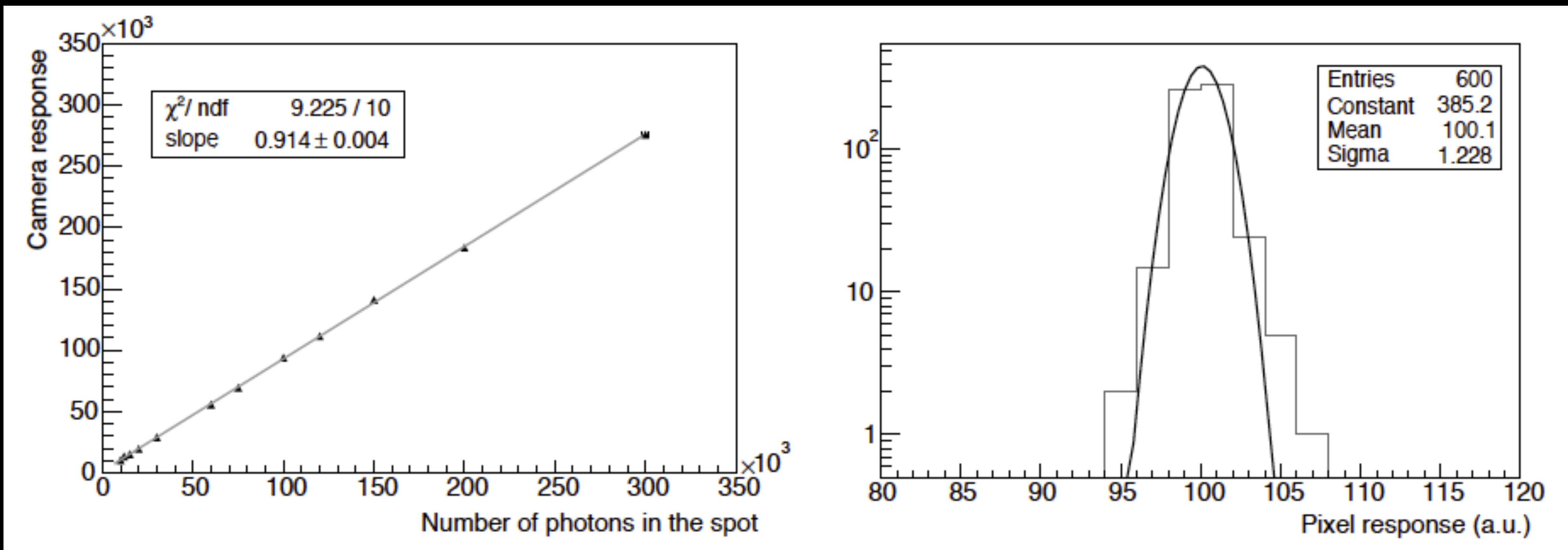
CMOS sensors provide very low noise together with high granularity and sensitivity



Equipped with a suitable large aperture (f/0.95) and a short focal lenght (20 mm) lens

CAMERA PERFORMANCE

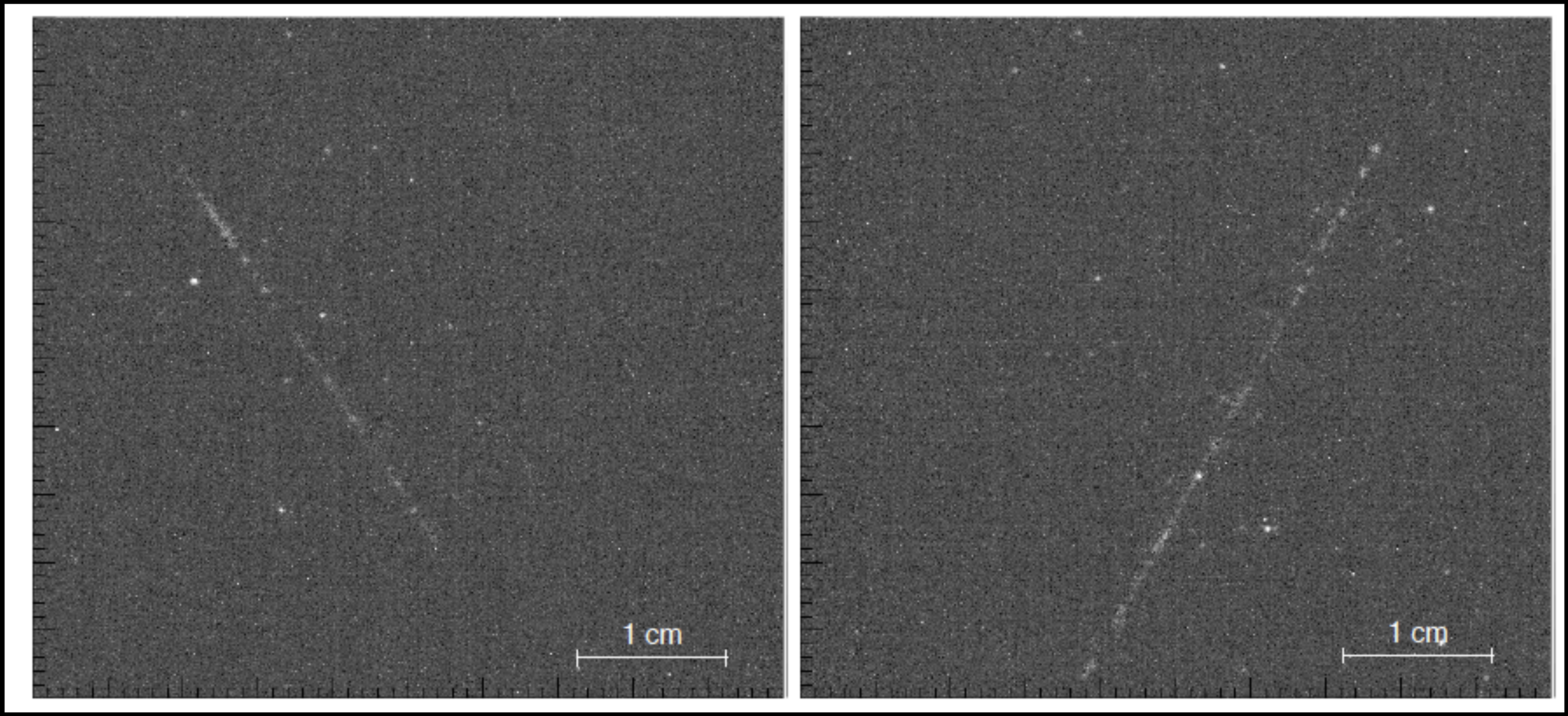
The photo-sensor was studied by means of a calibrated light source;



The camera behaviour is well linear in the whole studied range with a response of 0.91±0.01 counts per photon

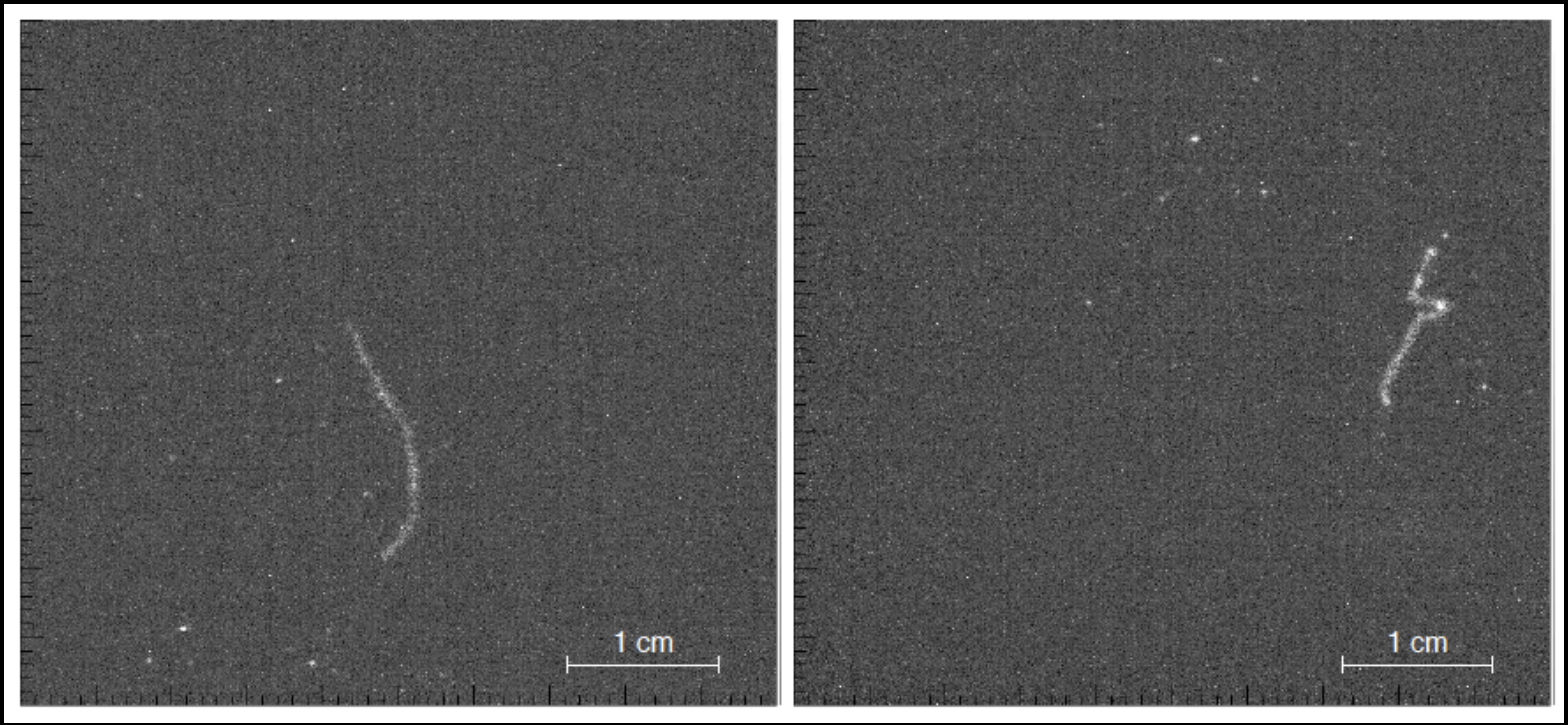
Fluctuations of the pedestal are lower than 2 counts, i.e. lower than two photons per pixel in good agreement with the expectations

JUNE 2015: COSMIC RAYS!



By means of this setup we were able to acquire several images of long and straight tracks as the above ones.

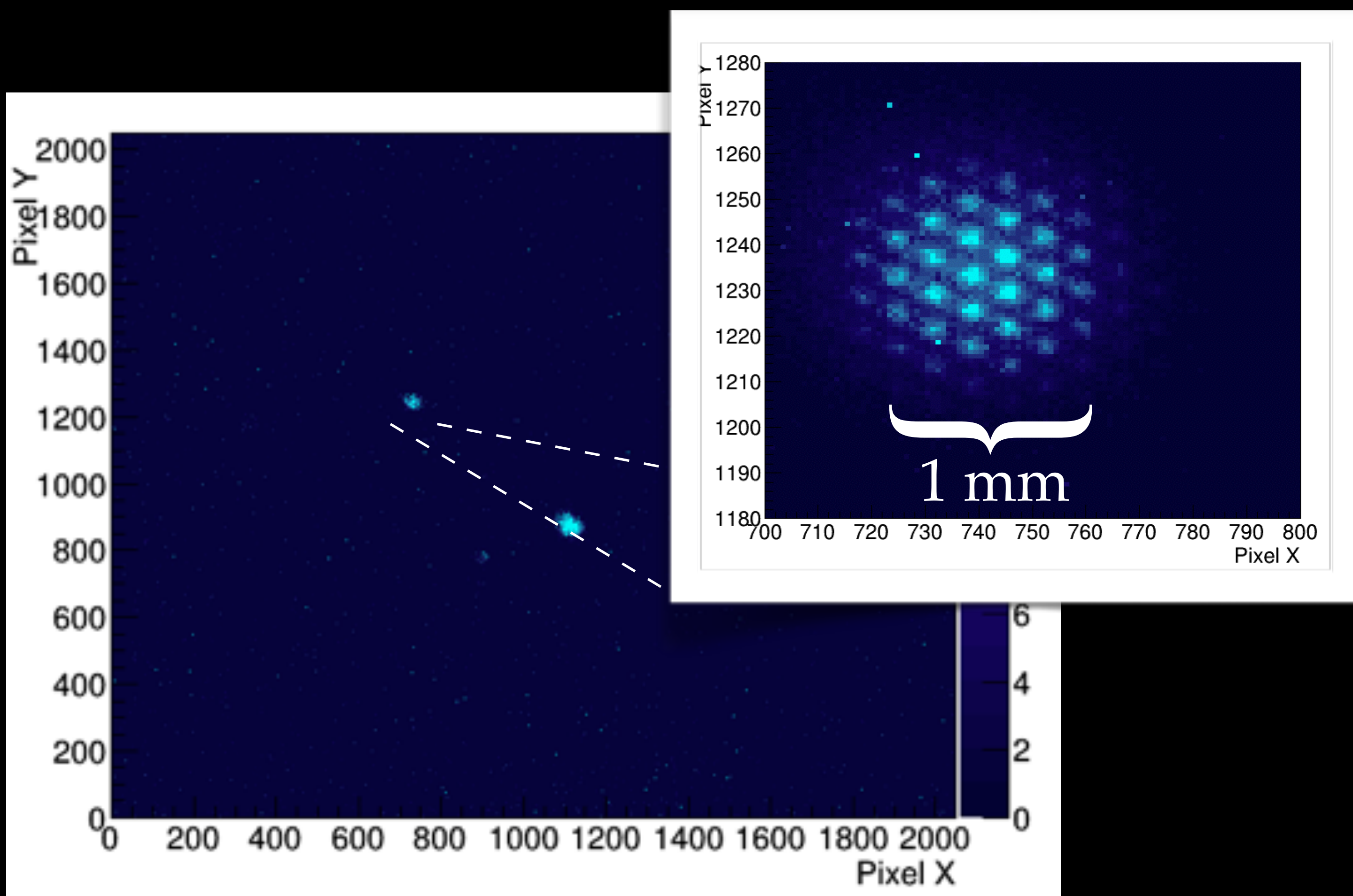
NATURAL RADIOACTIVITY

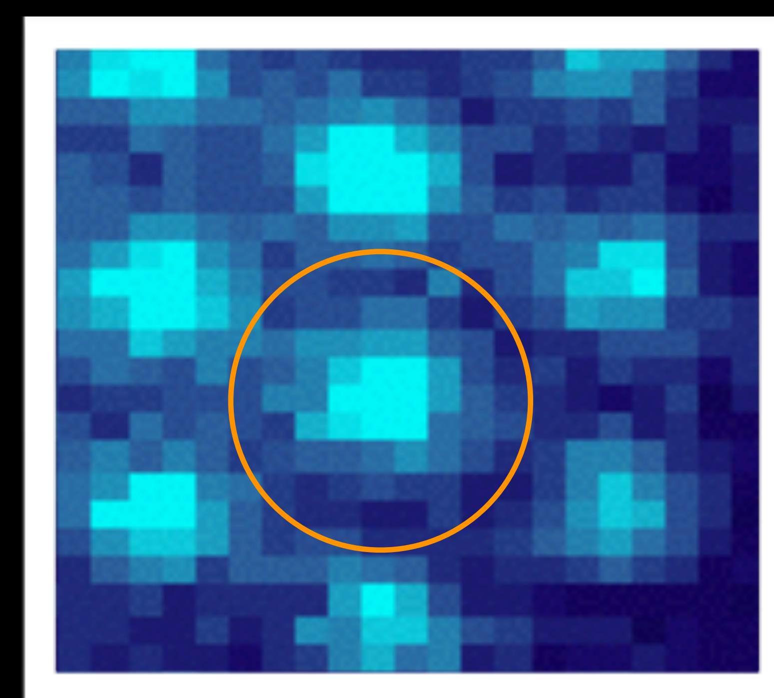


Several images of short, intense and curved tracks were acquired very likely due to ionizing electrons produced by natural radioactivity and traveling within the drift gap;

FIRST MEASUREMENTS

By using the camera we've been able to take pictures of several hot spots that appears when the three GEMs reach the high voltage working point, even without drawing a sizable leakage current;





Structure of GEM holes well visible

NOV 2015 & MAY 2016: TEST BEAM

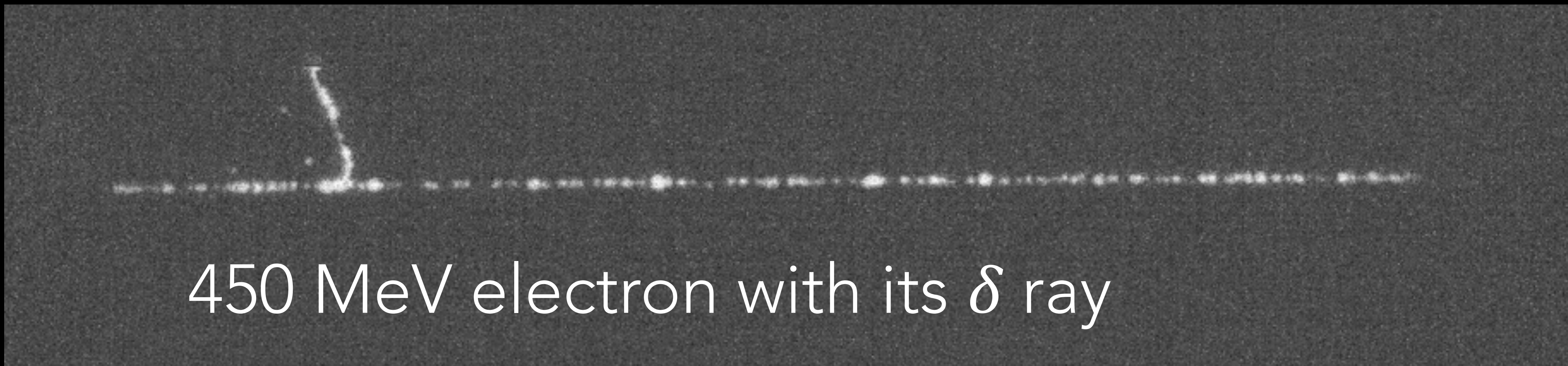
Two beam tests were performed at the Beam Facility in Frascati:

- electron bunches with a 50 Hz rate with highly variable amount of electrons per bunch: from “1” to “1000”;

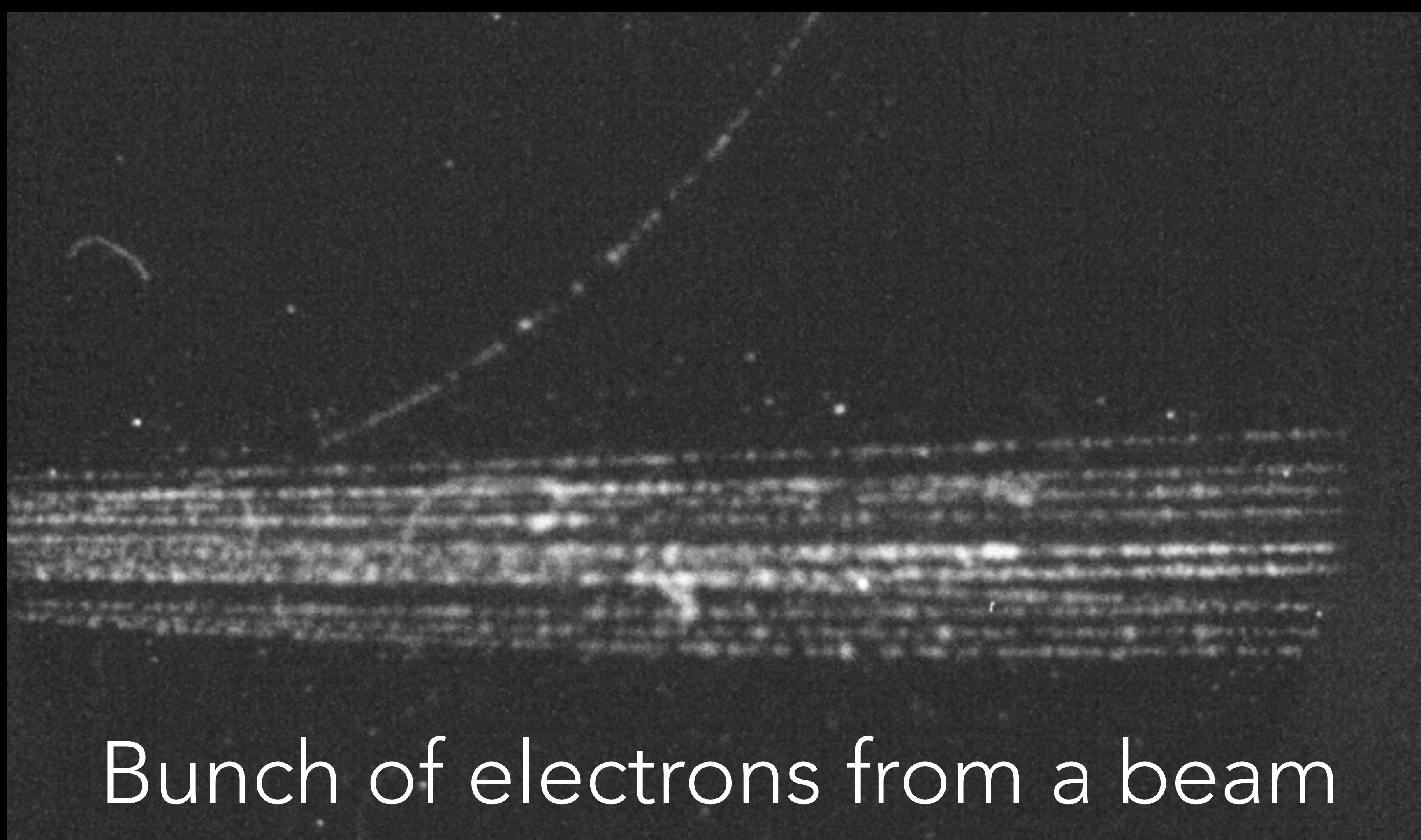
- energy of electrons can be selected in the range 30 MeV to 450 MeV;

- nominal beam space spread below 1 mm;

NOV 2015 & MAY 2016: TEST BEAM

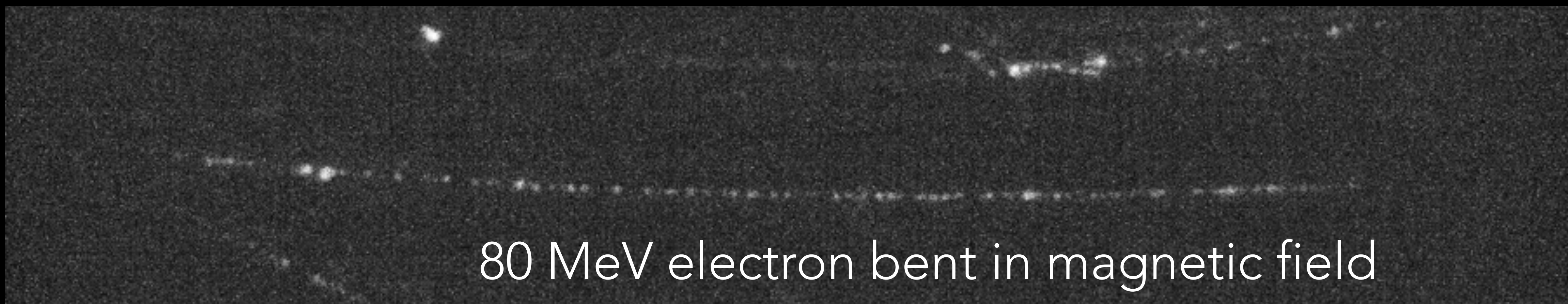


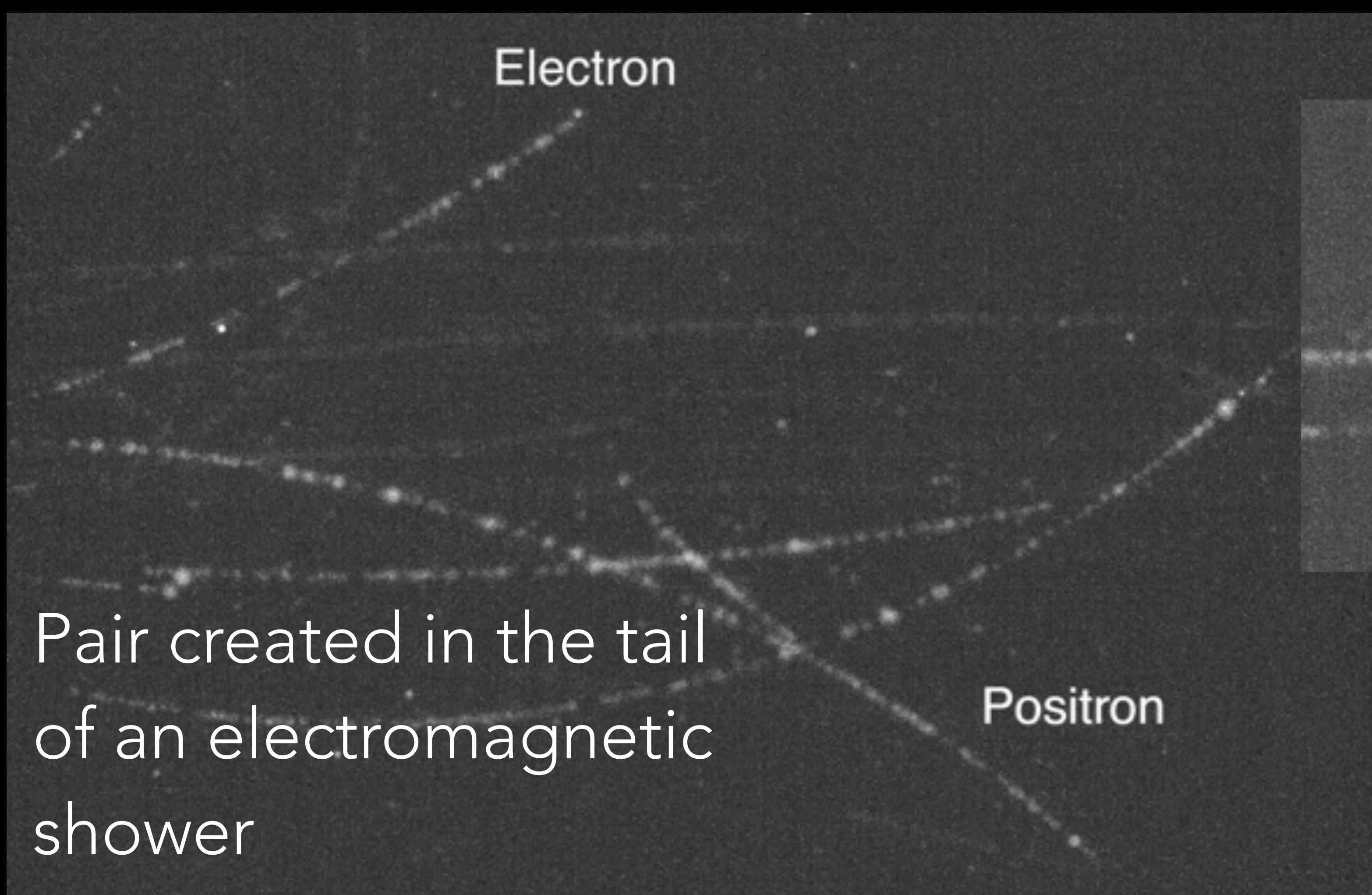
450 MeV electron with its δ ray



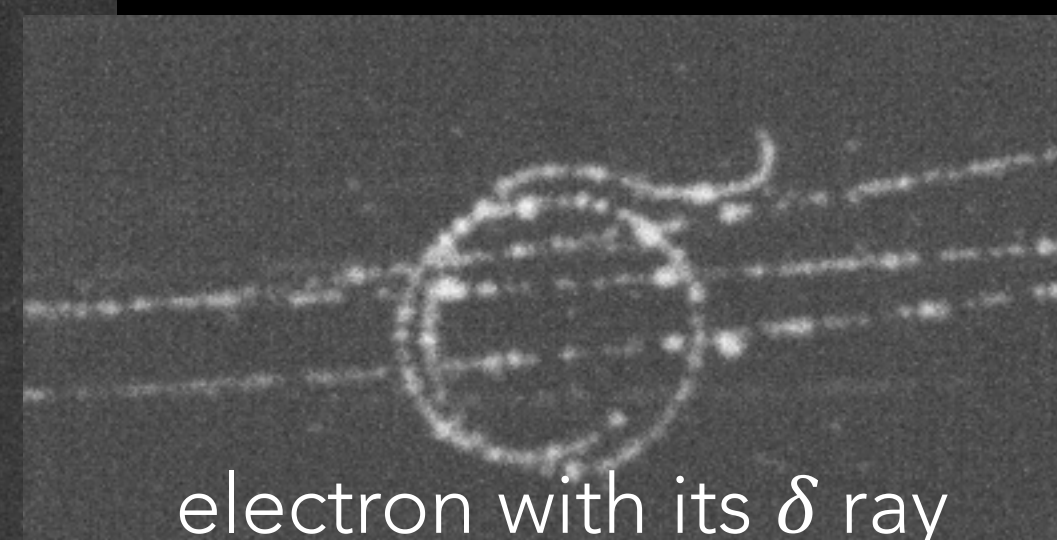
Bunch of electrons from a beam

0.2 MAGNETIC FIELD

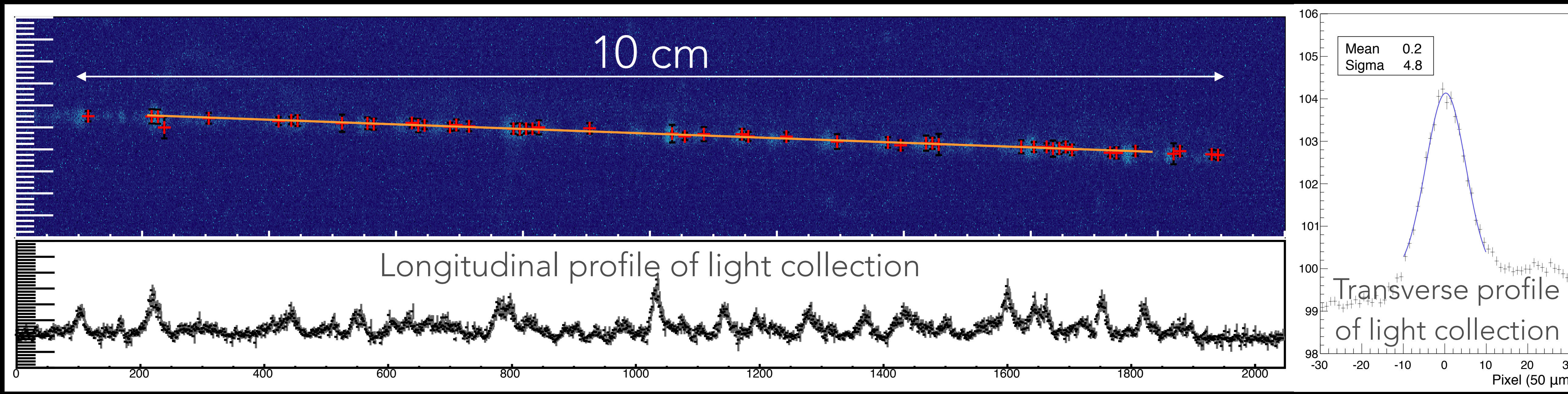

80 MeV electron bent in magnetic field



Pair created in the tail of an electromagnetic shower


electron with its δ ray

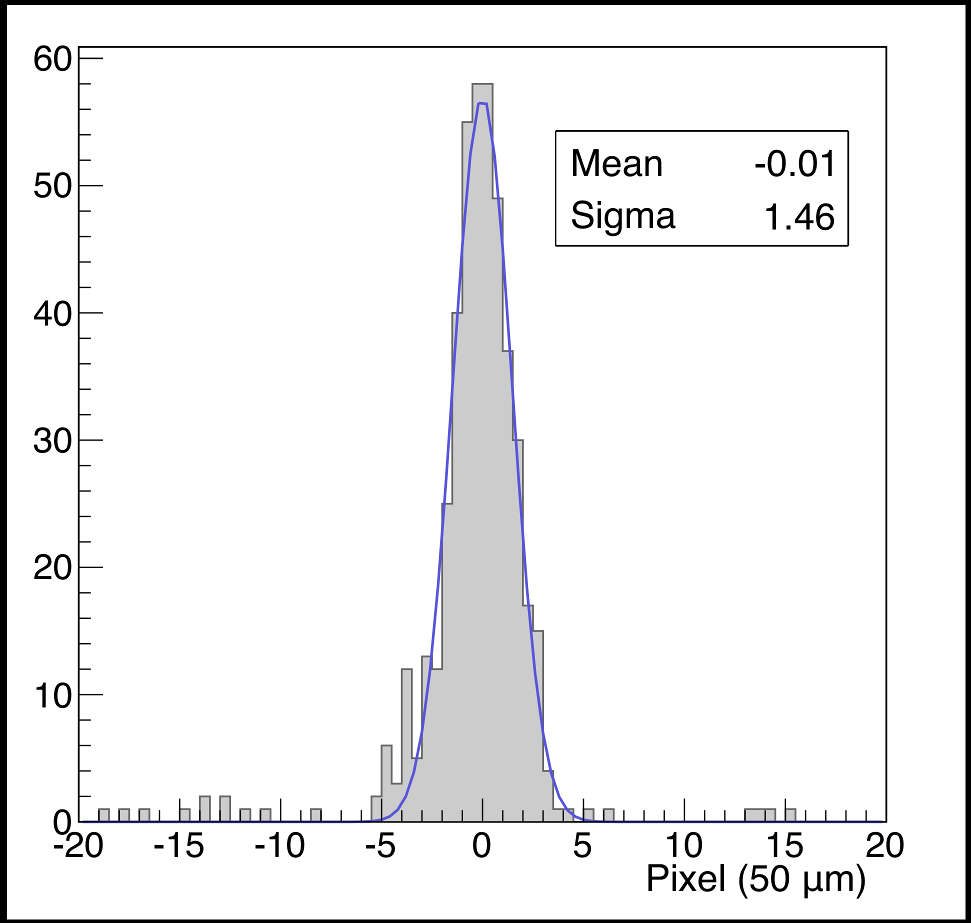
PERFORMANCE: TRACKING



About 1000 photons are detected per track millimeter. Cluster structure is visible.

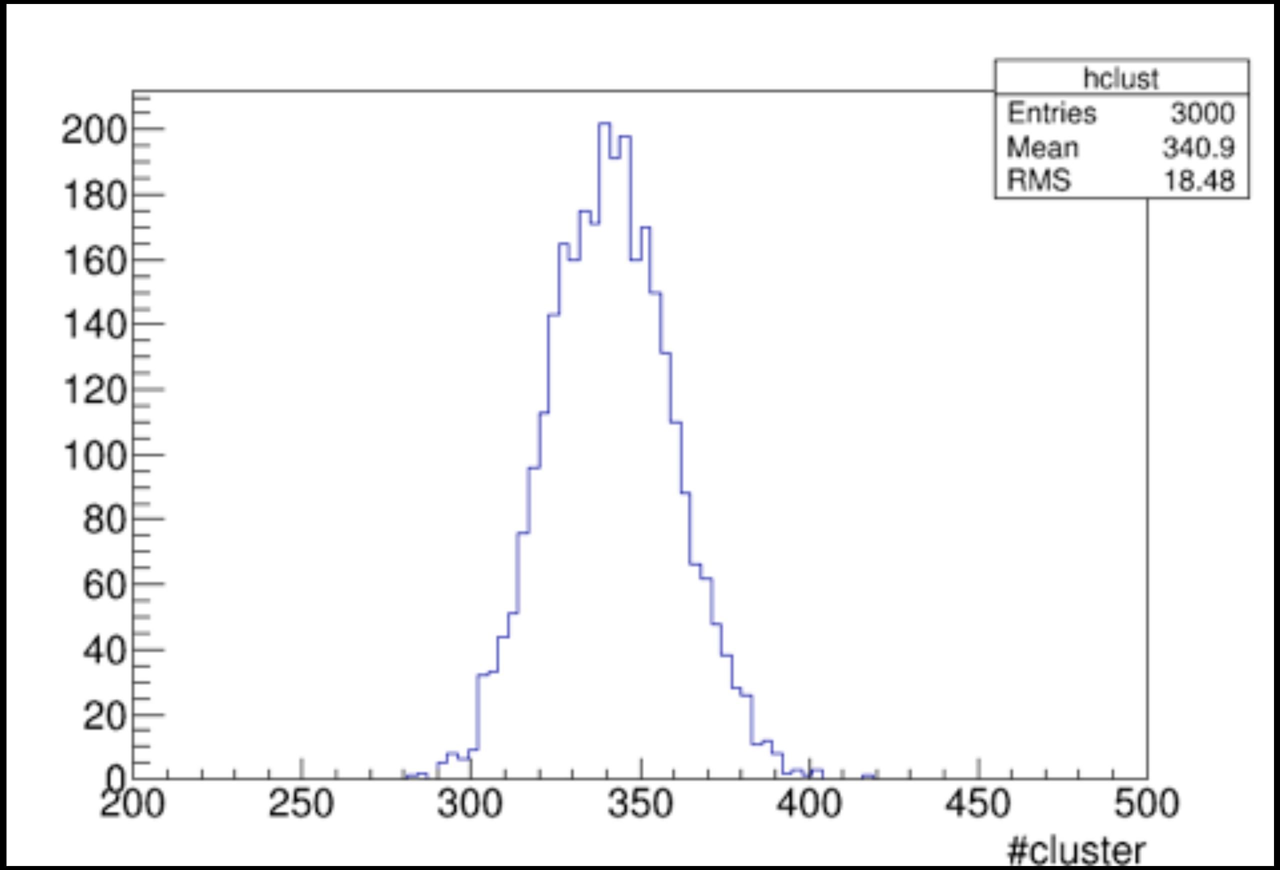
Transverse light collection has a good gaussian shape with a sigma of 250 µm.

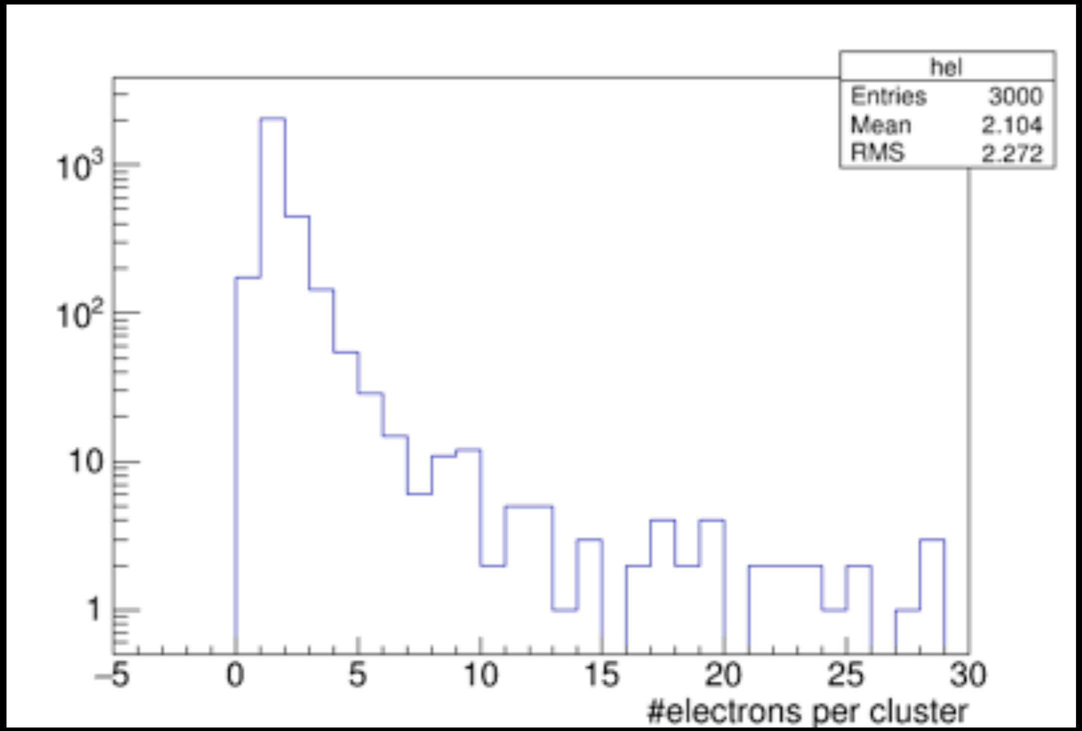
Distribution of residuals from the track has a sigma of 70 µm.



GAS GAIN

The gain of He/CF_4 mixture was studied starting from the Garfield evaluation of the number of primaries produced by the 450 MeV electrons of the beam: 341 clusters with about 2 electrons each.





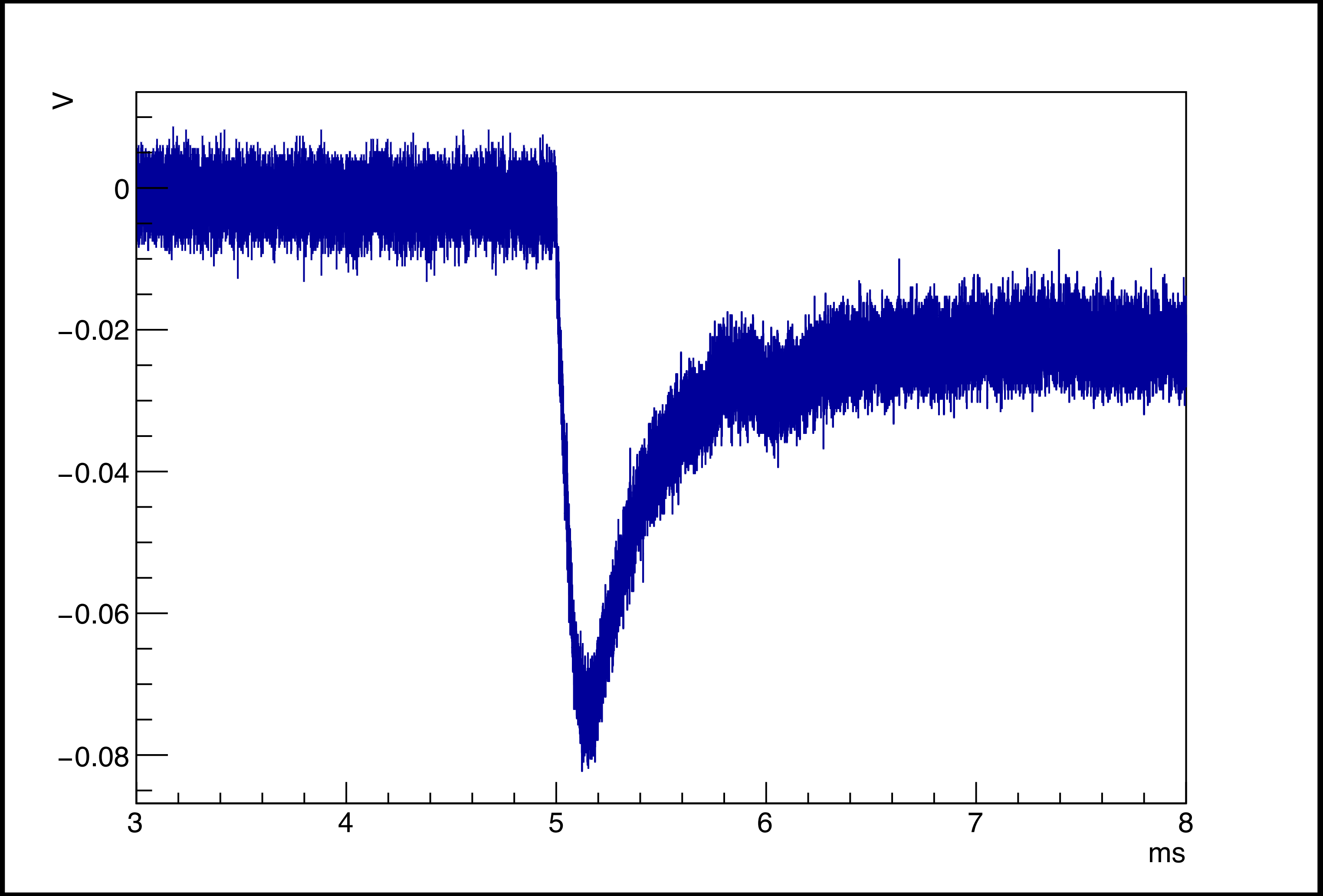
680 primary electrons in 10 cm

(i.e. 7 primary electrons per mm)

GAS GAIN

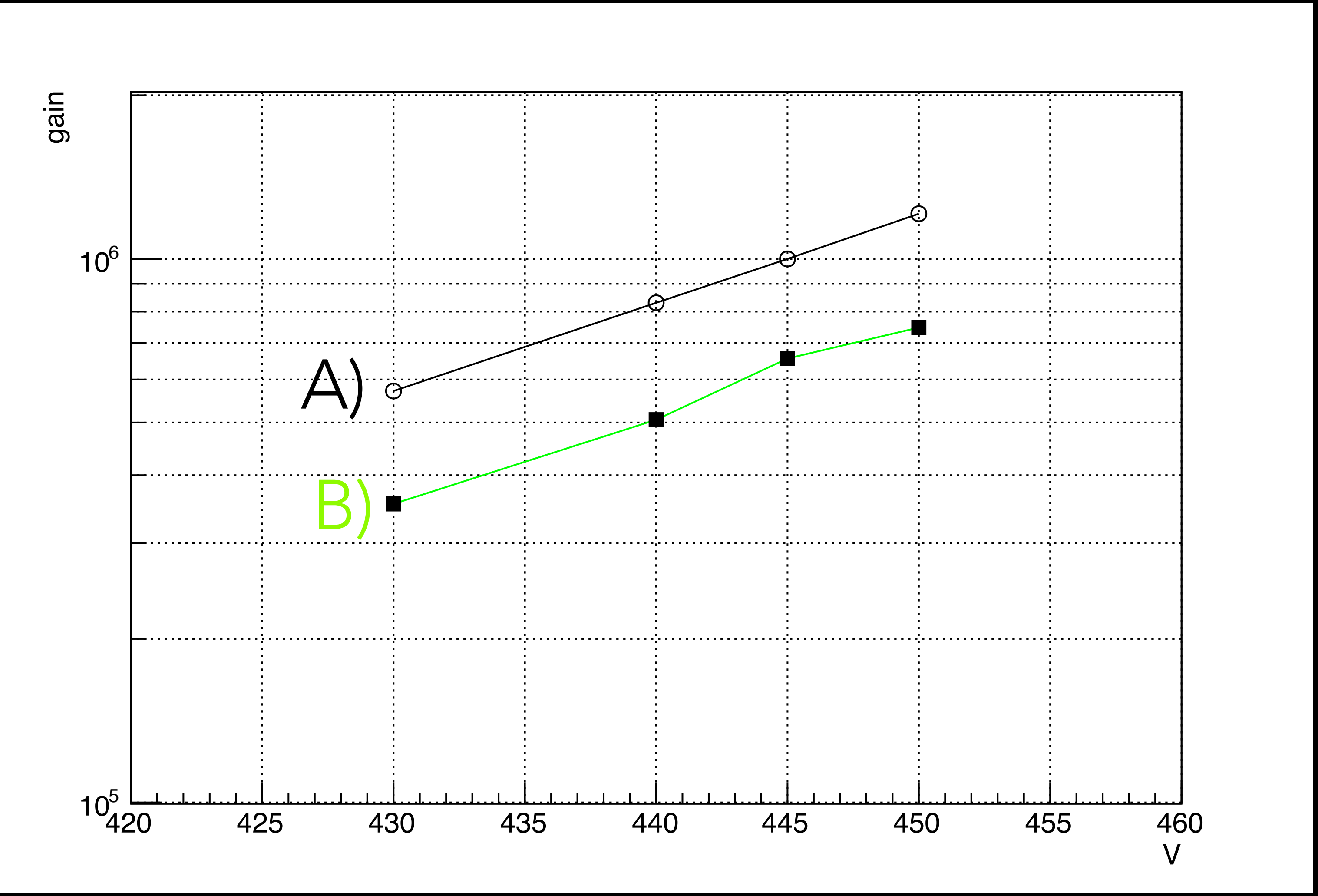
In our detector no extraction field is foreseen below the last GEM;

The electric signals were acquired by a 10 GS/s scope on the bottom electrode of the third GEM;



GAS GAIN

The obtained results show that we are working with quite high gains



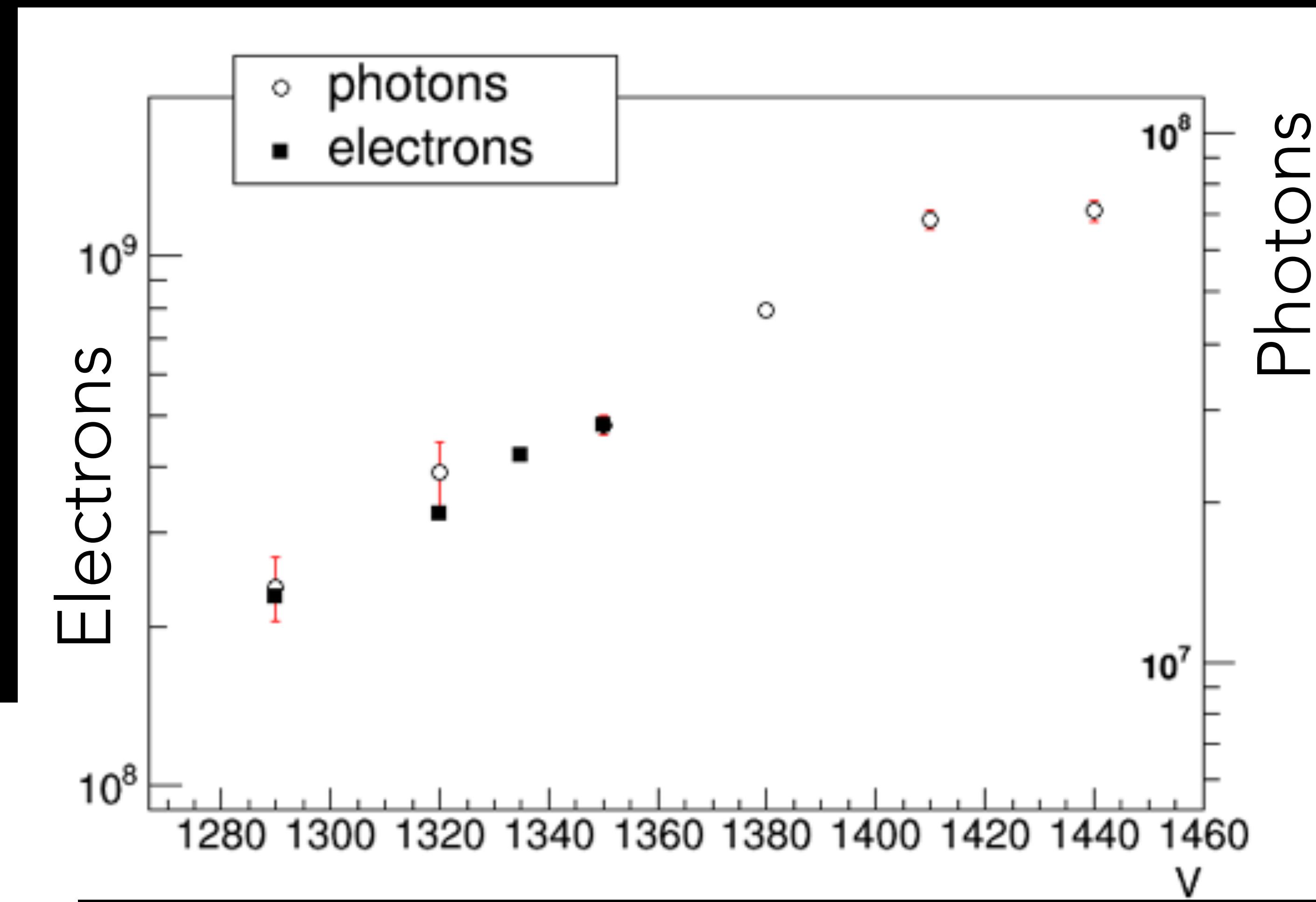
A better transparency can increase the amount of collected charge by a factor 2.

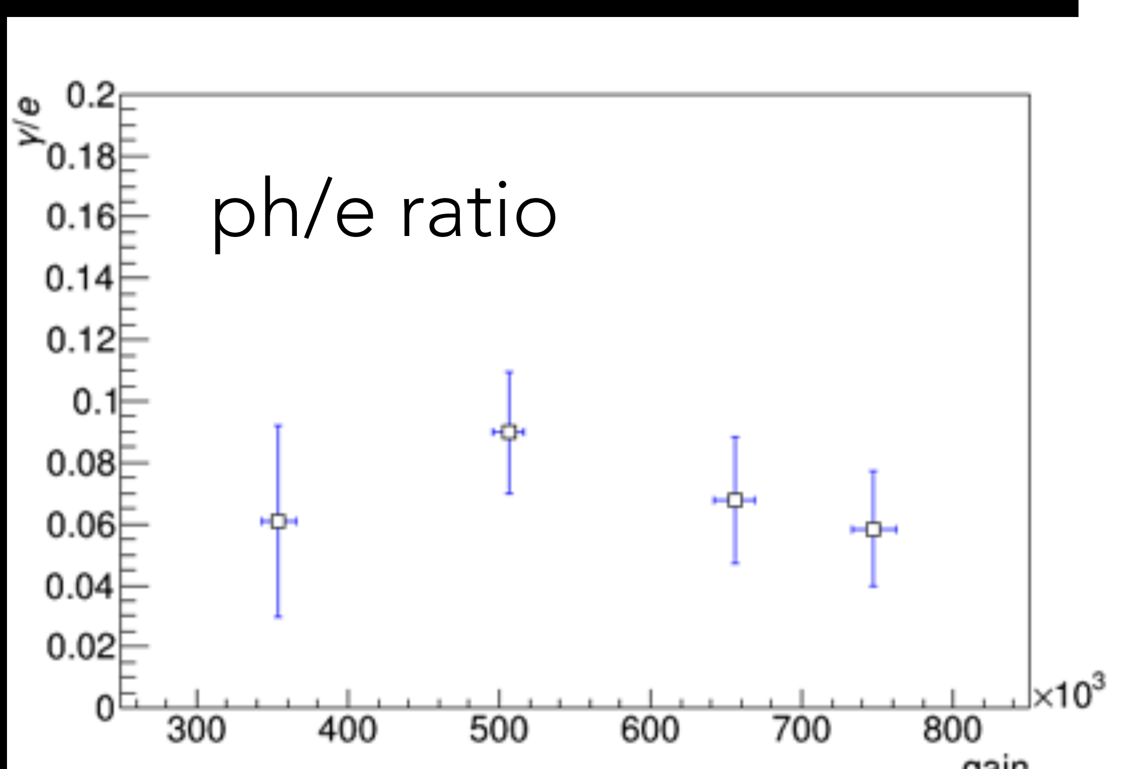
A) E_d=1.5 kV/cm and E_t=2.0 kV/cm

B) E_d=1.0 kV/cm and E_t=1.5 kV/cm

GAIN & LIGHT YIELD

The number of photons and electrons produced was evaluated for different GEM voltages

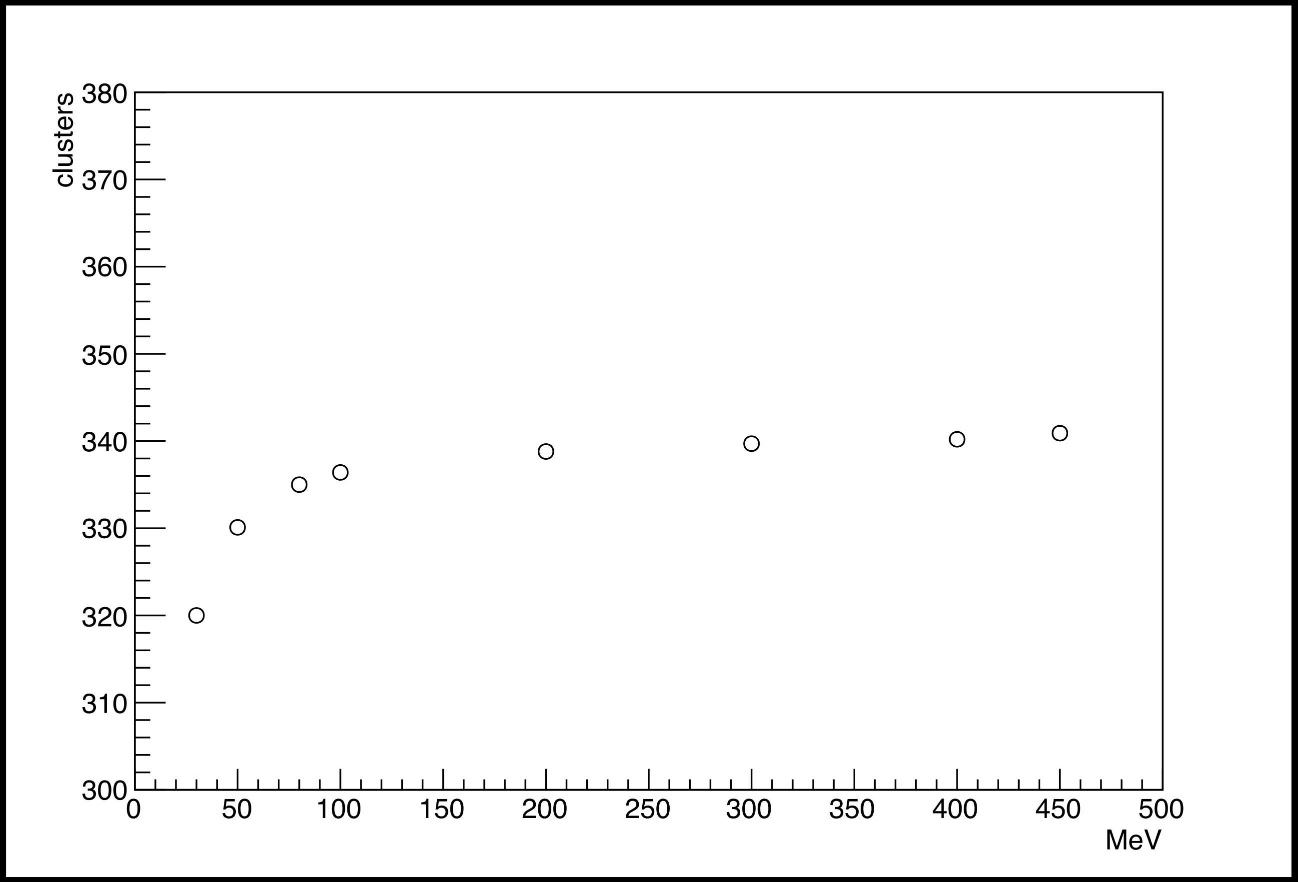




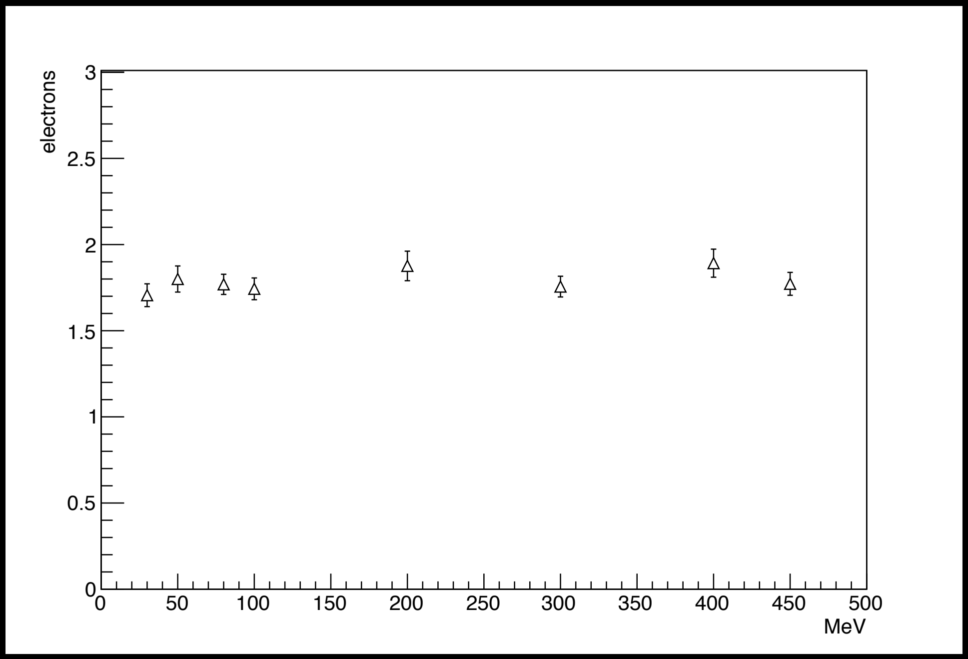
A constant ratio of about 0.07 photons per electron was found in the whole studied range.

LIGHT YIELD & BEAM ENERGY

By means of Garfield the average number of clusters produced in 10 cm of He/CF_4 (60/40) was evaluated for different beam energies



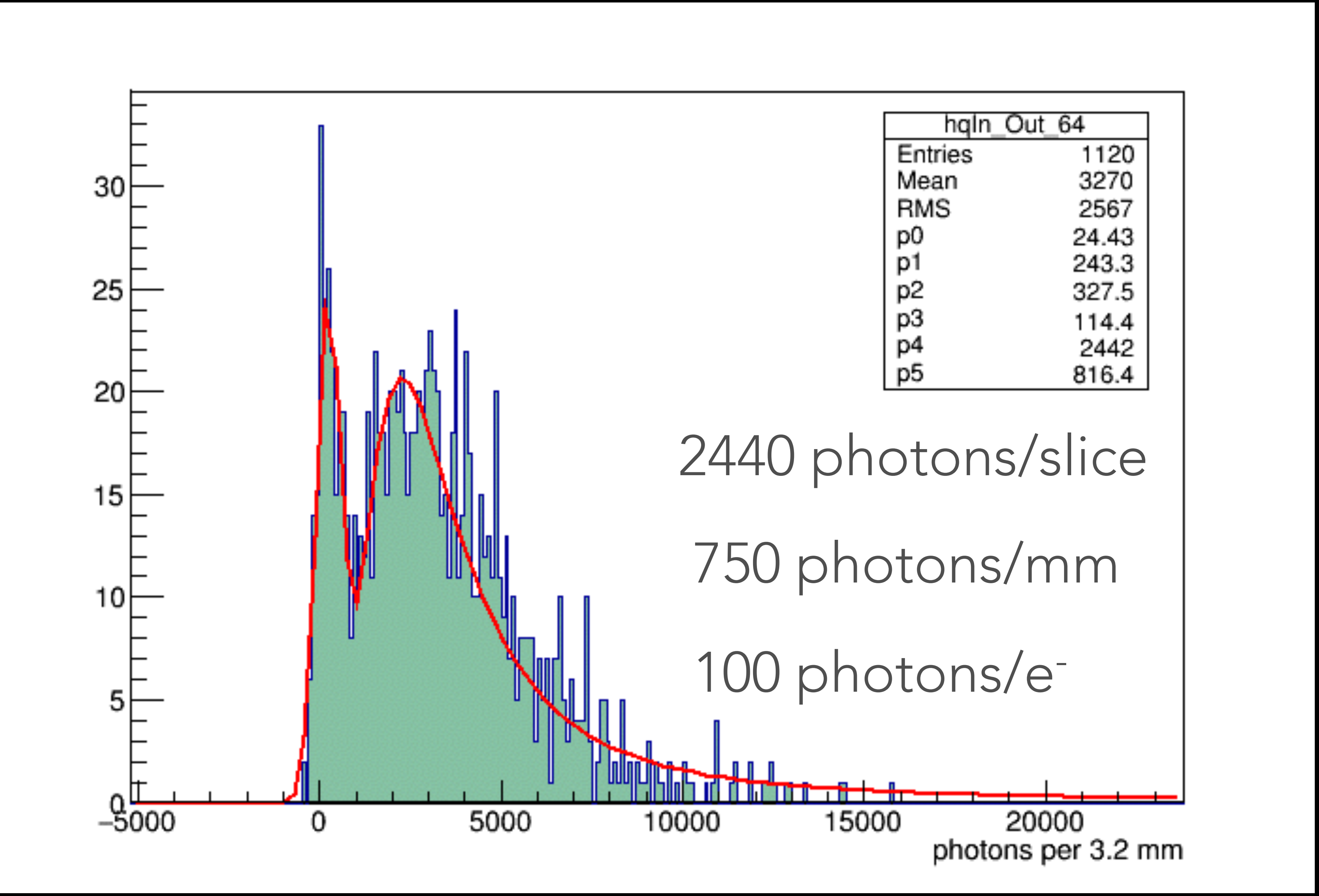
From 30 MeV to 450 MeV an increase in the amount of clusters of about 6% is expected while the average number of electrons per cluster is stable.



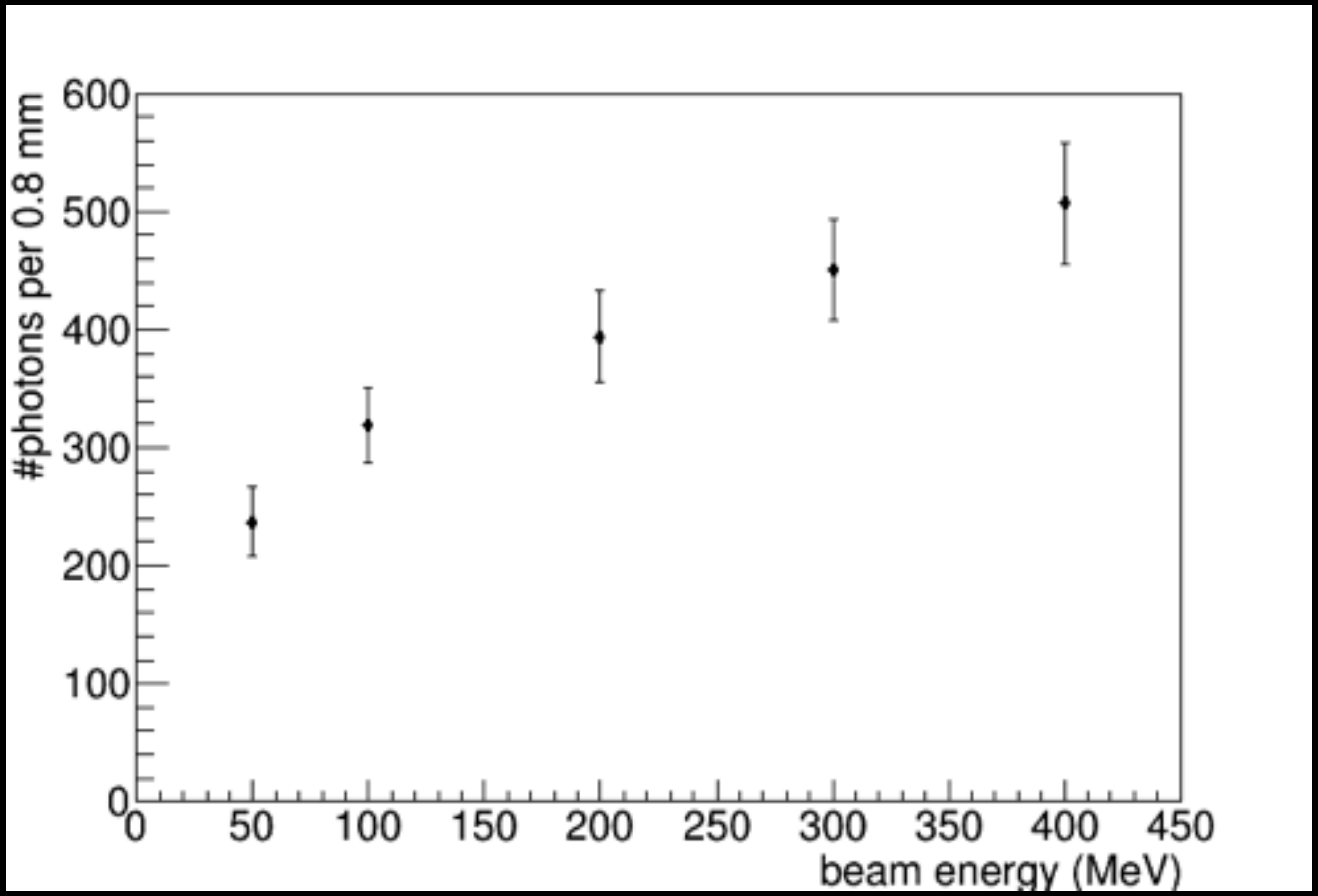
The increase in the total amount of primary charge is expected to result in an increase of the collected light.

LIGHT YIELD & BEAM ENERGY

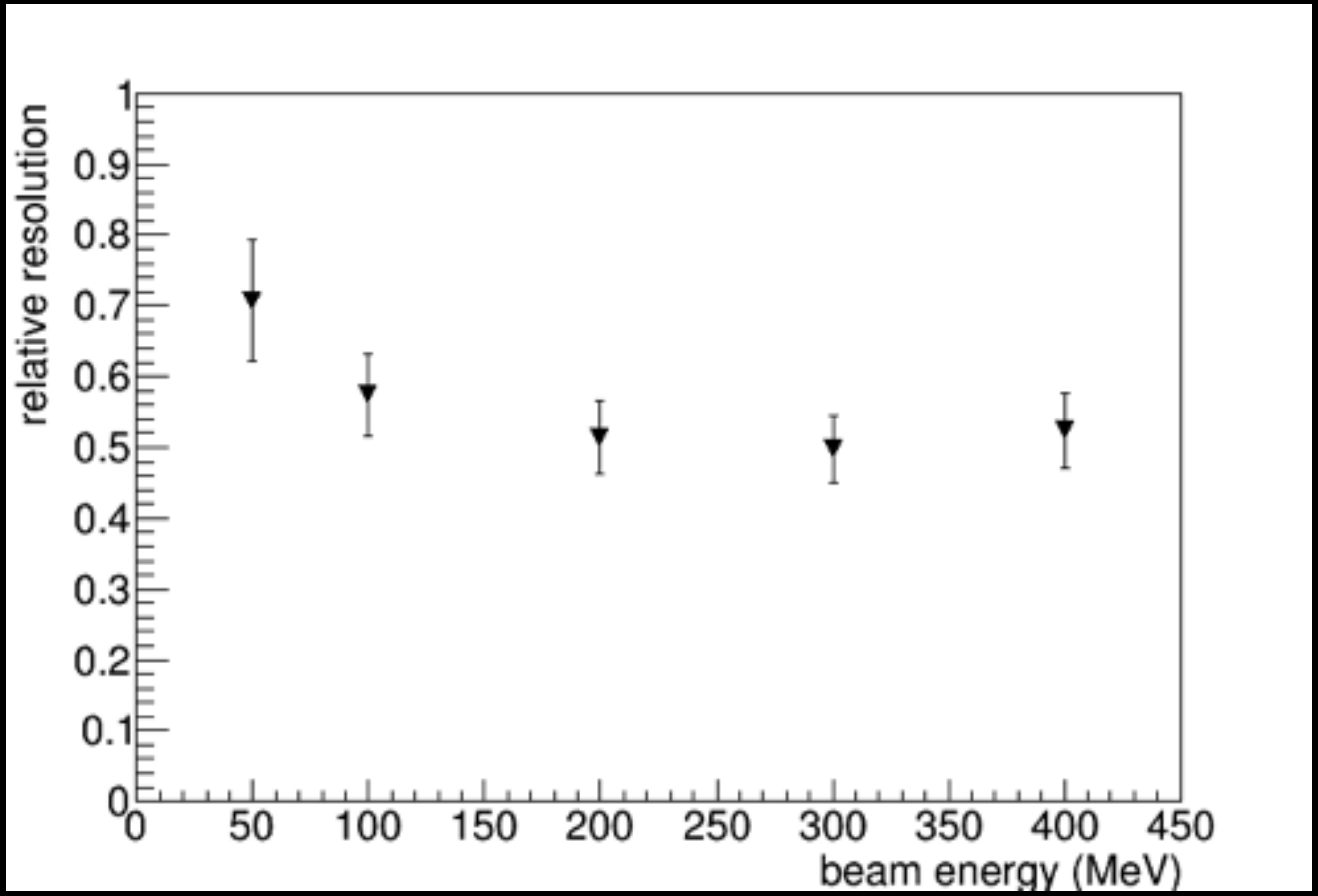
The plots show the distribution of the light collected in 3.2 mm slices for a beam energy of 450 MeV.



LIGHT YIELD & RESOLUTION



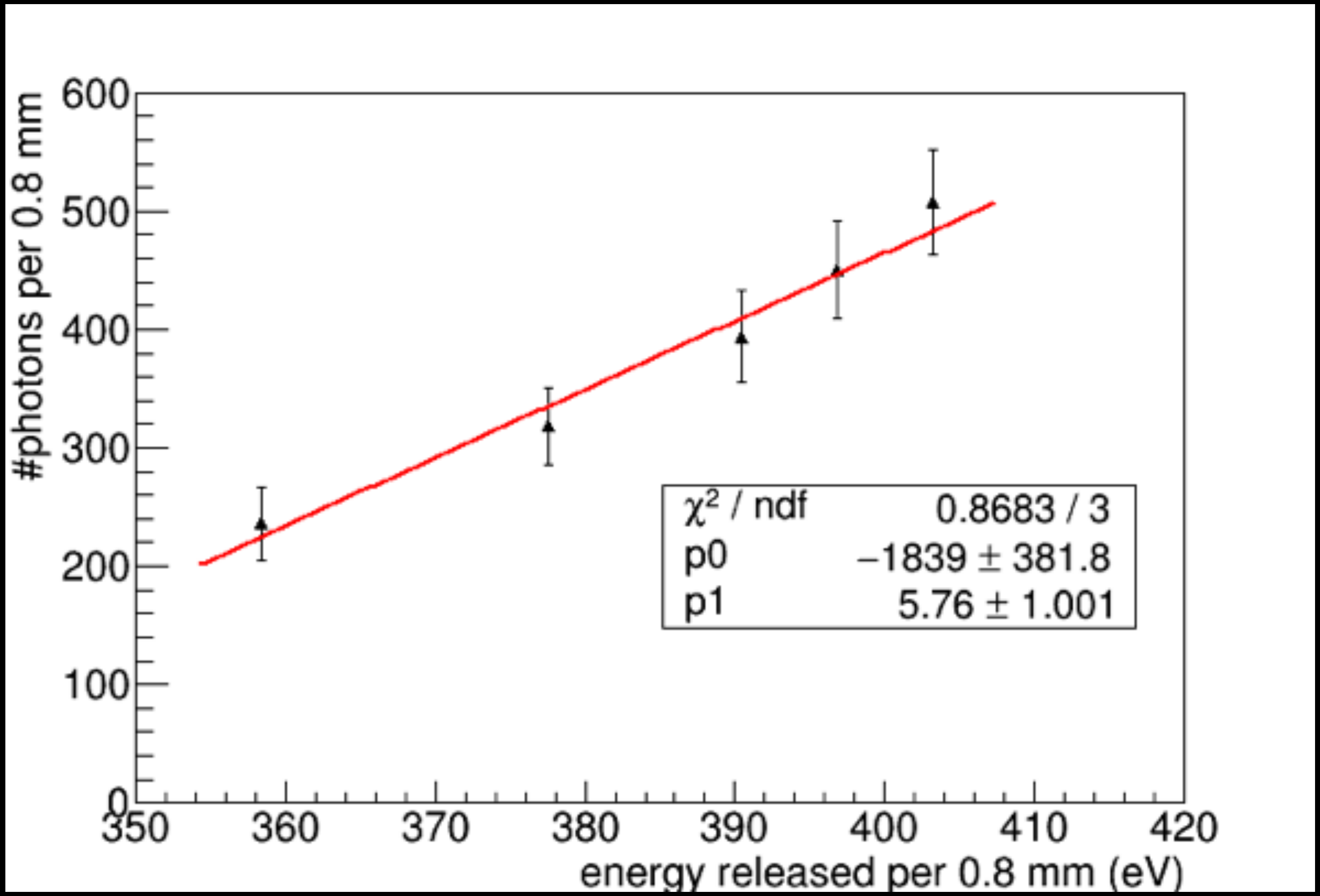
The light collected in 0.8 mm slices as a function of the beam energy.



Relative fluctuation of the light collected in 0.8 mm slices as a function of the beam energy.

LIGHT YIELD & BEAM ENERGY

The plots show the light collected in 0.8 mm slices as a function of the energy released per slice according to the Bethe-Block formula.

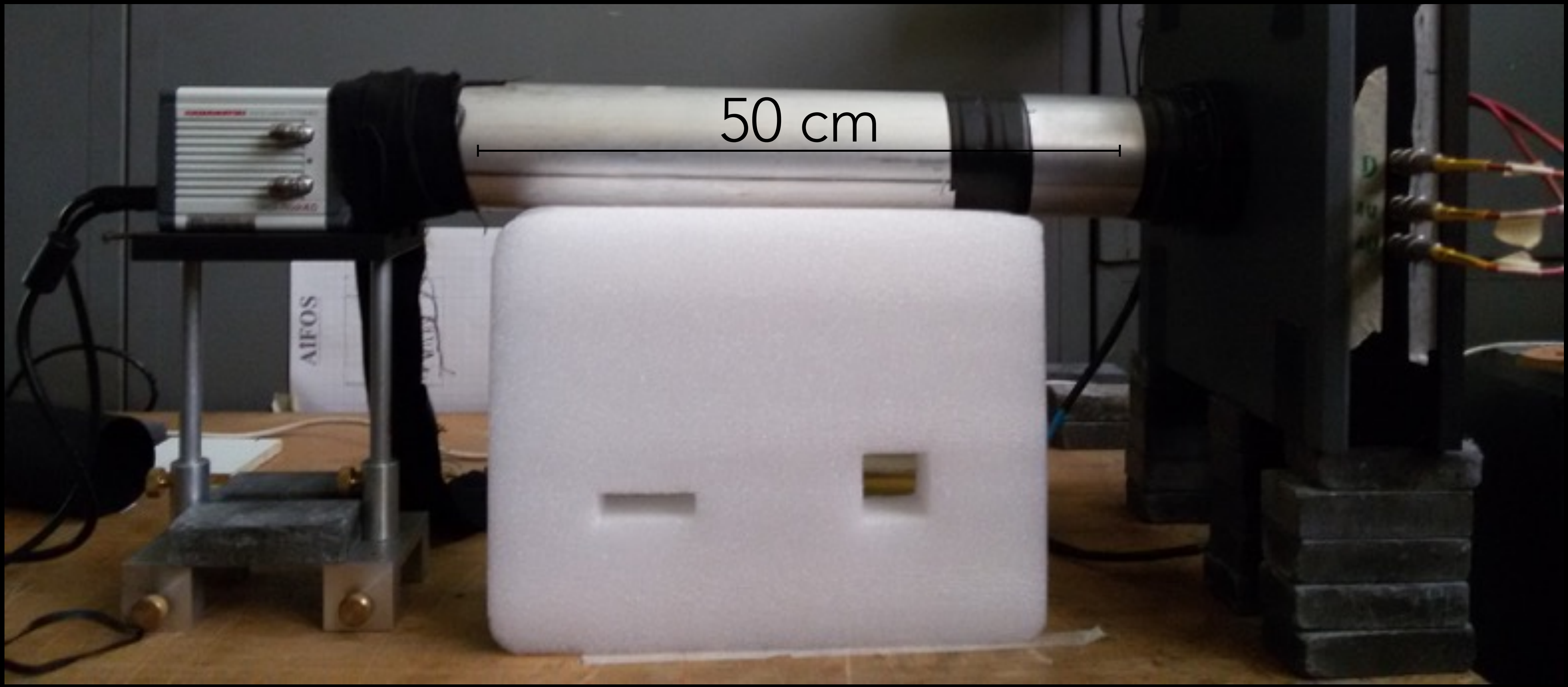


The measured number of photons per slice increases following the energy release calculated.

About 6 photons are collected per eV released.

LIGHT COLLECTION & DISTANCE

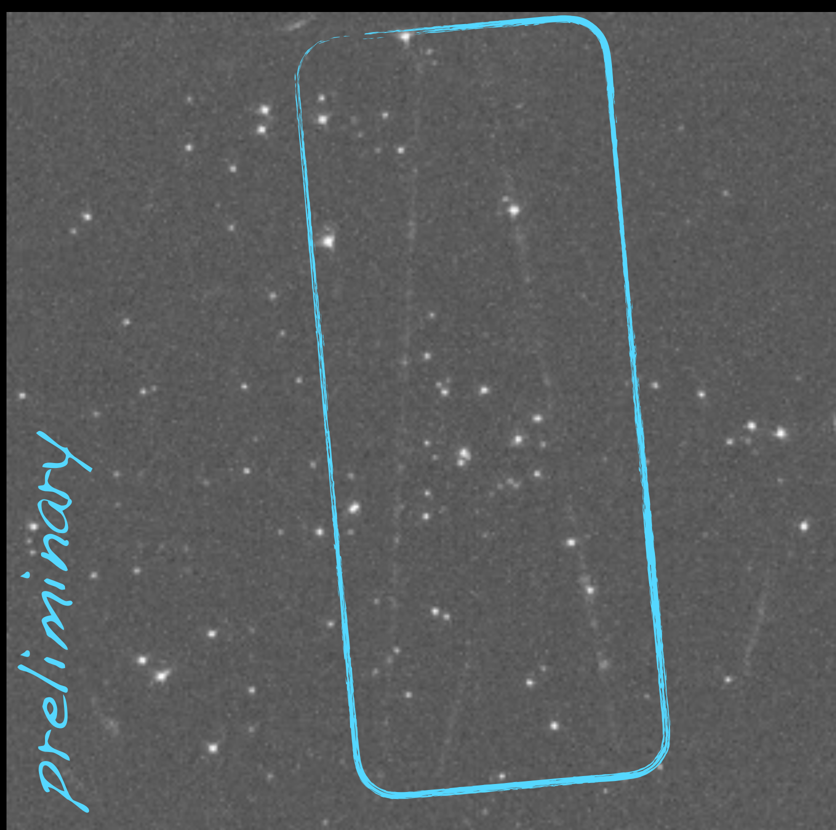
What it is the maximum area that can be acquired by a single 1x1 cm^2 optical sensor? i.e. how far can we put the camera?



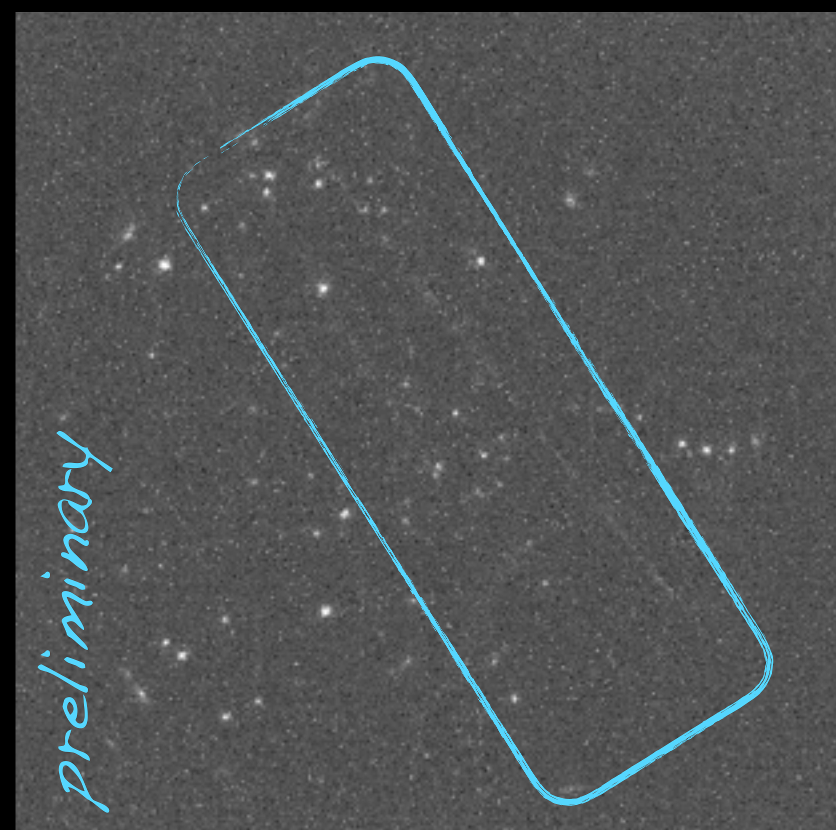
LIGHT COLLECTION & DISTANCE

Since we are working with a 2 cm focal length lens, each 20 cm a demagnification of 10 is obtained.

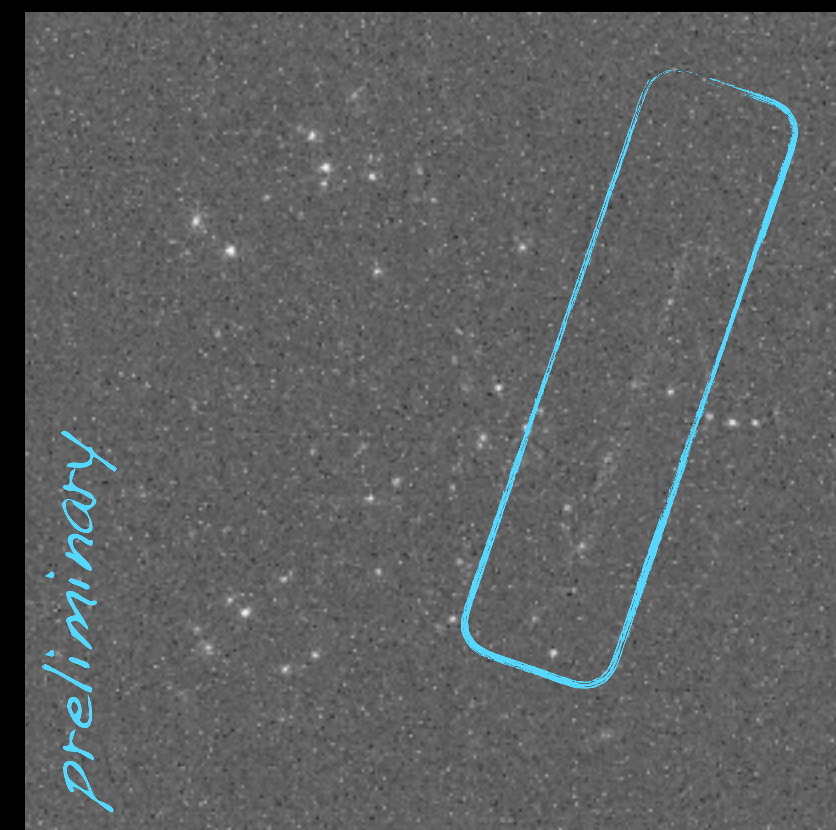
Distance = 40 cm
Covered area = 20x20 cm^2
Effective pixel size = 100 x 100 μm^2



Distance = 80 cm
Covered area = 40x40 cm^2
Effective pixel size = 200 x 200 μm^2



Distance = 100 cm
Covered area = 50x50 cm^2
Effective pixel size = 250 x 250 μm^2



From preliminary analysis it seems that we loose a 20% of light each 20 cm.

FUTURE STEPS

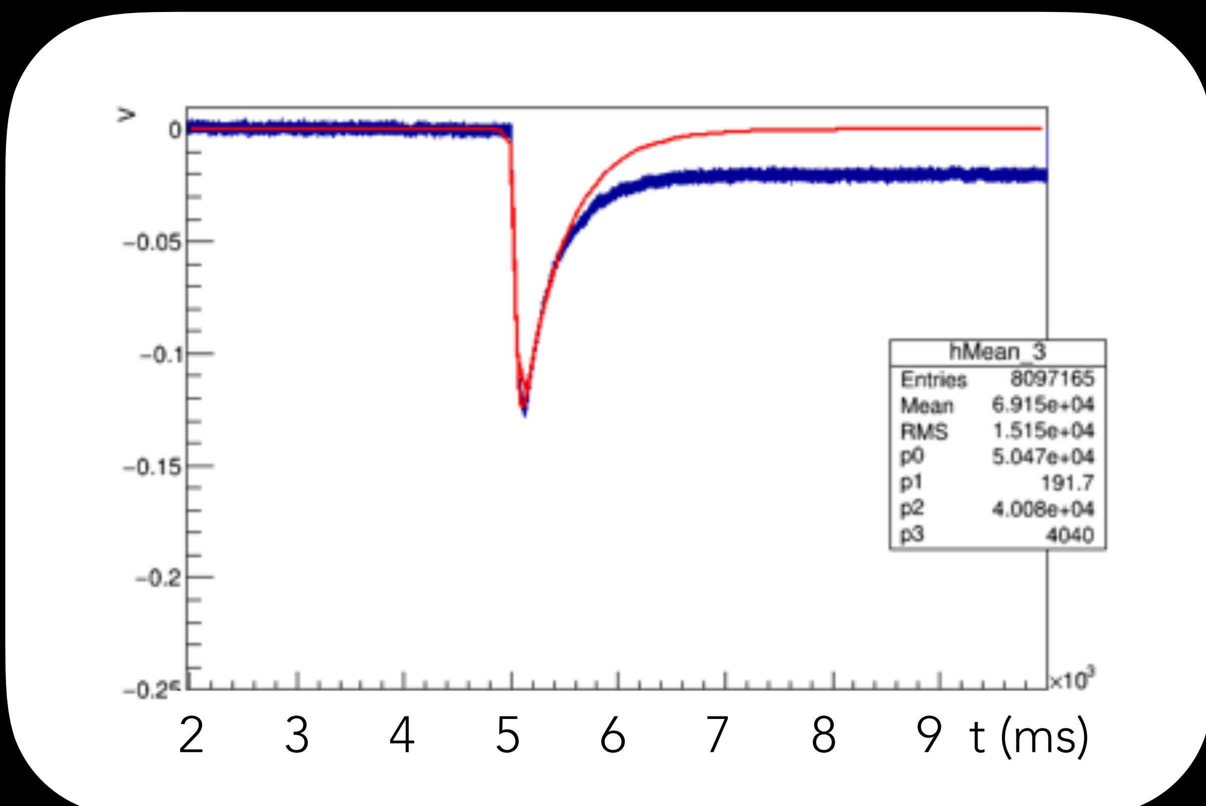
A Test Beam is ongoing at BTF in December to study the light collection as a function of geometry (distance, aperture, angle) on beam;

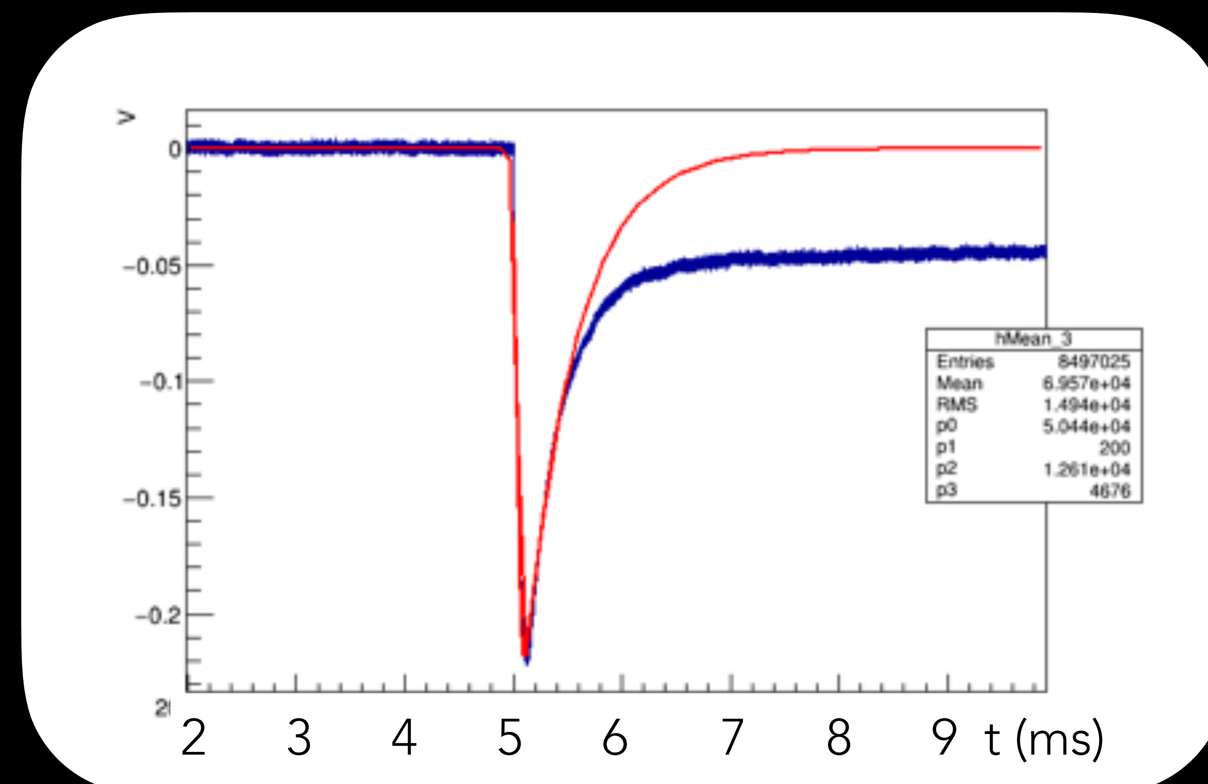
R&D in the framework of the CYGNUS collaboration for the DM search:

- Studies of new and exotic gas mixture (SF_6 based) allowing to exploit the negative ion drift technique.
- Studies of the detector performance and light yield in low pressure (50-100 Torr) conditions to allow visible nuclear recoils

GAS GAIN

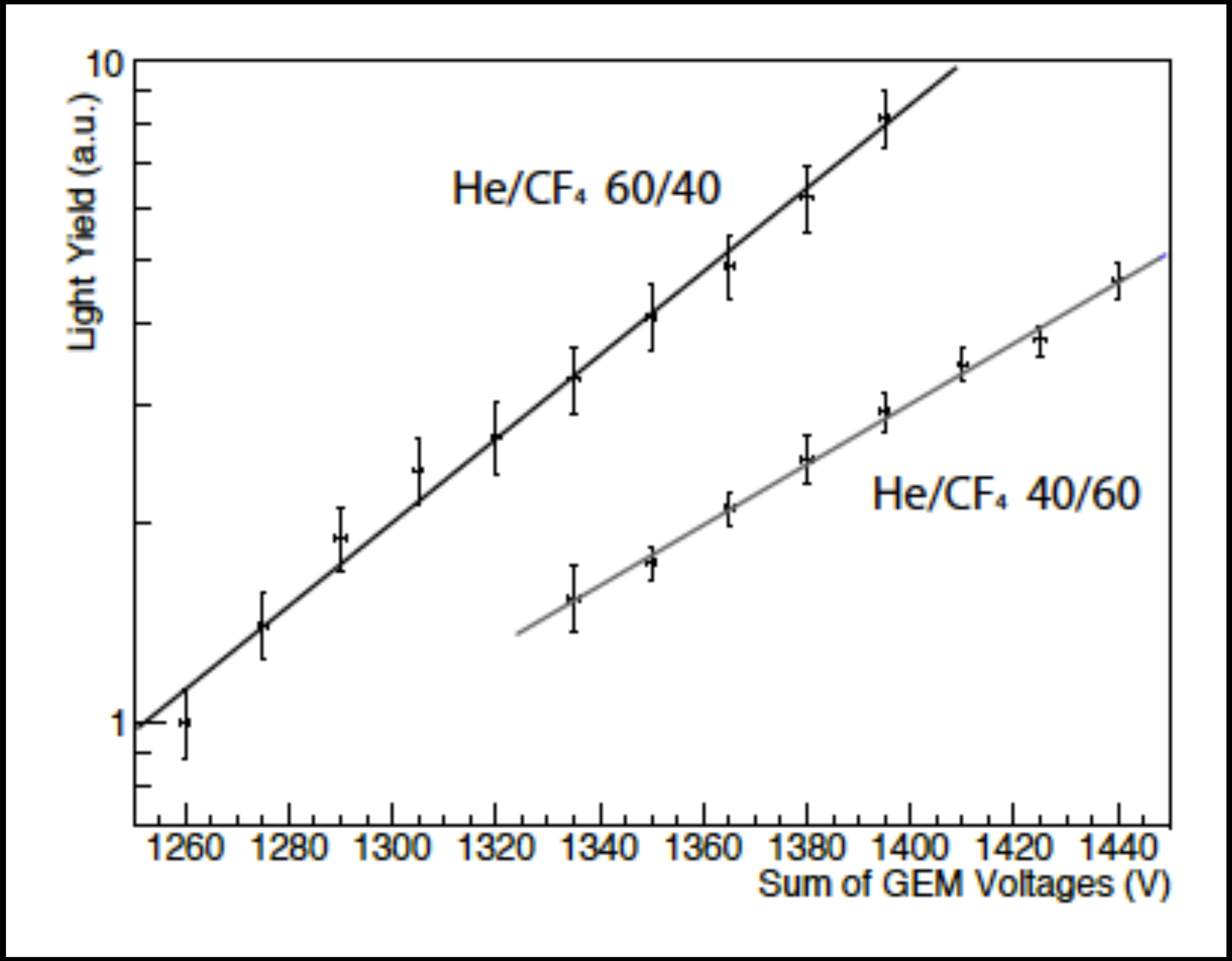
By averaging all signals due to a single track events is possible to reduce the fluctuations of the waveforms





Due to the presence of this unexpected tail, we made a fit (Fermi+exponential) on the average signal and integrated it to extract the produced charge.

LIGHT YIELD



While a 60% of CF_4 allowed to reach higher voltages,the mixture with 40% CF_4 showed a total light collection more than two times larger in the whole studied range.